

ARTYKUŁ OGŁĄDOWY/REVIEW PAPER

Wpłynęło/Submitted: 25.02.2009 • Zaakceptowano/Accepted: 01.06.2009

© Akademia Medycyny

***Neostigmine as a reversal agent:
Effects and side-effects***

Leo H.D.J. Booij¹, Leon Drobnić²

¹ Department of Anesthesiology, Radboud University Nijmegen, The Netherlands

² Department of Anaesthesiology and Intensive Therapy, Poznań University of Medical Sciences, Poland



References/Piśmiennictwo

1. Griffith HR, Johnson GE. The use of curare in general anesthesia. *Anesthesiology* 1942; 3: 412-20.
2. Cullen SC. Clinical and laboratory observations on the use of curare during inhalation anesthesia. *Anesthesiology* 1944; 5: 166-73.
3. Gray TC, Halton J. A milestone in anaesthesia? *Proc Roy Soc Med* 1946; 39: 400-10.
4. Gray TC, Wilson F. The development and use of muscle relaxants in the United Kingdom. *Anesthesiology* 1959; 20: 519-29.
5. Booij LHDJ, Drobnić L. Variability in the effect of muscle relaxants. Factors involved in the pharmacodynamic profile of neuromuscular blocking agents. *Anestezjologia i Ratownictwo* 2009; 3: 144-53, 154-84.
6. Booij LHDJ, Drobnić L. To reverse or not to reverse? The risk of residual neuromuscular blockade. *Anestezjologia i Ratownictwo* 2009; 3: 42-56.
7. Pedersen SE, Cohen JB. d-Tubocurarine binding sites are located at alpha-gamma and alpha-delta subunit interfaces of the nicotinic acetylcholine receptor. *Proc Natl Acad Sci USA* 1990; 87: 2785-9.
8. Placzek AN, Grassi F, Papke T, Mayer EM, Papke RL. A single point mutation confers properties of the muscle-type nicotinic acetylcholine receptor to homomeric $\alpha 7$ receptors. *Mol Pharmacol* 2004; 66: 169-77.
9. Faria M, Oliveira L, Timoteo MA, Lobo MG, Correia-De-Sa' P. Blockade of neuronal facilitatory nicotinic receptors containing alpha 3 beta 2 subunits contribute to tetanic fade in the rat isolated diaphragm. *Synapse* 2003; 49: 77-88.
10. Jonsson M, Dabrowski M, Gurley DA, Larsson O, Johnson EC, Fredholm BB, et al. Activation and inhibition of human muscular and neuronal nicotinic acetylcholine receptors by succinylcholine. *Anesthesiology* 2006; 104: 724-33.
11. Yodlowski EH, Mortimer JT. The relationship between receptor occlusion and the frequency sweep electromyogram during competitive neuromuscular blockade. *Anesthesiology* 1981; 34: 23-8.
12. Rotundo RL. Expression and localization of acetylcholinesterase at the neuromuscular junction. *J Neurocytol* 2003; 32: 743-66.
13. Darvesh S, Hopkins DA, Geula C. Neurobiology of butyrylcholinesterase. *Nature Rev Neurosci* 2003; 4: 131-8.
14. Krasowski MD, McGehee DS, Moss J. Natural inhibitors of cholinesterases: implications for adverse drug reactions. *Can J Anaesth* 1997; 44: 525-34.
15. Dale HH. The action of certain esters and ethers of choline and their relation to muscarine. *J Pharmacol Exp Ther* 1914; 6: 147-90.
16. Loewi O, Navratil E. Über humorale Übertragbarkeit der Herznervenwirkung: X. Mitteilung. Über das Schicksal des Vagustoff. *Pflugers Arch Gesamte Physiol* 1926: 214.
17. Marnay A, Nachmansohn D. Choline esterase in voluntary muscle. *J Physiol* 1938; 92: 34-47.
18. Eccles JC, Katz B, Kuffler SW. Effect of eserine on neuromuscular transmission. *J Neurophysiol* 1942; 5: 211-21.
19. Lomo T, Massoulie J, Vigny M. Stimulation of denervated rat soleus muscle with fast and slow activity patterns induces different expression of acetylcholinesterase molecular forms. *J Neurosci* 1985; 5: 1180-7.
20. Sketelj J, Crne-Finderle N, Brzin M. Influence of denervation on the molecular forms of junctional and extrajunctional acetylcholinesterase in fast and slow muscles of the rat. *Neurochem Int* 1992; 21: 415-21.
21. Sketelj J, Crne-Finderle N, Strukelj B, Trontelj JW, Pette D. Acetylcholinesterase mRNA level and synaptic activity in rat muscles depend on nerve-induced pattern of muscle activation. *J Neurosci* 1998; 18: 1944-52.
22. Rotundo RL, Fambrough DM. Secretion of acetylcholinesterase: Relation to acetylcholine receptor metabolism. *Cell* 1980; 22: 595-602.
23. Rotundo RL & Fambrough DM. Synthesis, transport and fate of acetylcholinesterase in cultured chick embryo muscle cells. *Cell* 1980; 22: 583-94.

24. McMahan UJ, Sanes JR, Marshall LM. Cholinesterase is associated with the basal lamina at the neuromuscular junction. *Nature* 1978; 271: 172-4.
25. Cartaud A, Strohlic L, Guerra M, Blanchard B, Lambergeon M, Krejci E, Cartaud J, Legay C. MuSK is required for anchoring acetylcholinesterase at the neuromuscular junction. *J Cell Biol* 2004; 165: 505-15.
26. Kimbell LM, Ohno K, Engel AG, Rotundo RL. C-terminal and heparin-binding domains of collagenic tail subunit are both essential for anchoring acetylcholinesterase at the synapse. *J Biol Chem* 2004; 279: 10997-1005.
27. Arikawa-Hirasawa E, Rossi SG, Rotundo RL, Yamada Y. Absence of acetylcholinesterase at the neuromuscular junctions of perlecan-null mice. *Nat Neurosci* 2002; 5: 119-23.
28. Martinez-Pena y Valenzuela I, Hume RI, Krejci E, Akaaboune M. In vivo regulation of acetylcholinesterase insertion at the neuromuscular junction. *J Biol Chem* 2005; 280: 31801-8.
29. Sussman JL, Harel M, Frolow F, Oefner C, Goldman A, Toker L, Silman I. Atomic structure of acetylcholinesterase from *Torpedo californica*: a prototypic acetylcholine-binding protein. *Science* 1991; 253: 872-9.
30. Layer PG. Comparative localization of acetylcholinesterase and pseudocholinesterase during morphogenesis of the chicken brain. *Proc Natl Acad Sci USA* 1983; 80: 6413-7.
31. Silman I, Sussman JL. Acetylcholinesterase: 'classical' and 'non-classical' functions and pharmacology. *Curr Opin Pharmacol* 2005; 5: 293-302.
32. Li B, Sibley JA, Tieu A, Xie W, Schopfer LM, Hammond P, Brimijoin S, Hinrichs SH, Lockridge O. Abundant tissue butyrylcholinesterase and its possible function in the acetylcholinesterase knockout mouse. *J Neurochem* 2000; 75: 1320-31.
33. Rotundo RL. Expression and localization of acetylcholinesterase at the neuromuscular junction. *J Neurocytol* 2003; 32: 743-66.
34. McGehee DS, Krasowski MD, Fung DL, Wilson B, Gronert GA, Moss J. Cholinesterase inhibition by potato glycoalkaloids slows mivacurium metabolism. *Anesthesiology* 2000; 93: 510-9.
35. Viby-Mogensen J, Hanel HK. Prolonged apnoea after suxamethonium. An analysis of the first 225 cases reported to the Danish Cholinesterase Research Unit. *Acta Anaesthesiol Scand* 1978; 22: 371-80.
36. Lockridge O, Bartels CF, Vaughan TA, Wong CK, Norton SE, Johnson LL. Complete amino acid sequence of human serum cholinesterase. *J Biol Chem* 1987; 262: 549-57.
37. Jenkins T, Balinsky D, Patient DW. Cholinesterase in plasma: First reported absence in the Bantu; half-life determination. *Science* 1967; 156: 1748-50.
38. Østergaard D, Viby-Mogensen J, Hanel HK, Skovgaard LT. Half-life of plasma cholinesterase. *Acta Anaesthesiol Scand* 1988; 32: 266-9.
39. Cook DR, Stiller RL, Weakly JN, Chakravorti S, Brandom BW, Welch RM. In vitro metabolism of mivacurium chloride (BW B1090U) and succinylcholine. *Anesth Analg* 1989; 68: 452-6.
40. Sikorav JL, Krejci E, Massoulie J. cDNA sequences of *Torpedo marmorata* acetylcholinesterase: Primary structure of the precursor of a catalytic subunit; existence of multiple 5'-untranslated regions. *EMBO J* 1987; 6: 1865-73.
41. Rotundo RL, Gomez AM, Fernandez Valle C, Randall WR. Allelic variants of acetylcholinesterase: Genetic evidence that all acetylcholinesterase forms in avian nerves and muscles are encoded by a single gene. *Proc Natl Acad Sci USA* 1988; 85: 7805-9.
42. Arpagaus M, Kott M, Vatsis KP, Bartels CF, La Du BN, Lockridge O. Structure of the gene for human butyrylcholinesterase. Evidence for a single copy. *Biochemistry* 1990; 29: 124-31.
43. Gaughan G, Park H, Priddle J, Craig I, Craig S. Refinement of the localization of human butyrylcholinesterase to chromosome 3q26.1-q26.2 using a PCR-derived probe. *Genomics* 1991; 11: 455-8.
44. Jasmin BJ, Lee RK, Rotundo RL. Compartmentalization of acetylcholinesterase RNA and enzyme at the vertebrate neuromuscular junction. *Neuron* 1993; 11: 467-77.
45. Merlie JP, Sanes JR. Concentration of acetylcholine receptor RNA in synaptic regions of adult muscle fibres. *Nature* 1985; 317: 66-8.
46. Motamed C, Fanen P, Feiss P, Kirov K, Duvaldestin P. Dose-response effect of serum butyrylcholinesterase activity after clinical doses of pancuronium. *Eur J Clin Pharmacol* 2008; 64: 1043-5.
47. Evans RT. Cholinesterase phenotyping: clinical aspects and laboratory applications. *CRS Crit Rev Clin Lab Sci* 1986; 23: 35-64.
48. Girard T, Kindler CH. Pharmacogenetics and anaesthesiology. *Curr Pharmacogenomics* 2004; 2: 119-35.
49. La Du BN. Butyrylcholinesterase variants and the new methods of molecular biology. *Acta Anaesthesiol Scand* 1995; 39: 139-41.
50. Lockridge O, Masson P. Pesticides and susceptible populations: People with butyrylcholinesterase genetic variants may be at risk. *Neurotoxicology* 2000; 21: 113-226.
51. Gätke MR, Viby-Mogensen J, Østergaard D, Bundgaard JR. Response to mivacurium in patients carrying the k variant in the butyrylcholinesterase gene. *Anesthesiology* 2005; 102: 503-8.
52. Bartels CF, Jensen FS, Lockridge O, van der Spek AFL, Rubinstein HM, Lubrano T, et al. DNA mutation associated with the human butyrylcholinesterase K-variant and its linkage to the atypical variant mutation and other polymorphic sites. *Am J Hum Genet* 1992; 50: 1086-103.
53. Petersen RS, Bailey PL, Kalameghan R, Ashwood ER. Prolonged neuromuscular block after mivacurium. *Anesth Analg* 1993; 76: 194-6.

54. Goudsouzian NG, d'Hollander AA, Viby-Mogensen J. Prolonged neuromuscular block from mivacurium in 2 patients with cholinesterase deficiency. *Anesth Analg* 1993; 77: 183-5.
55. Rosenberg MK, Lebennom-Mansour M. Markedly prolonged paralysis after mivacurium in a patient apparently heterozygous for the atypical and usual pseudocholinesterase alleles by conventional biochemical testing. *Anesth Analg* 1997; 84: 457-60.
56. Fox MH, Hunt PCW. Prolonged neuromuscular block associated with mivacurium. *Br J Anaesth* 1995; 74: 237-8.
57. Souza RL, Mikami LR, Maegawa RO, Chautard-Freire-Maia EA. Four new mutations in the BCHE gene of human butyrylcholinesterase in a Brazilian blood donor sample. *Mol Genet Metab* 2005; 84: 349-53.
58. Pantuck EJ. Plasma cholinesterase: gene and variations. *Anesth Analg* 1993; 77: 380-6.
59. Müller JS, Mihaylova V, Abicht A, Lochmüller H. Congenital myasthenic syndromes: spotlight on genetic defects of neuromuscular transmission. *Expert Rev Mol Med* 2007; 9: 1-20.
60. Ohno K, Engel AG, Brengman JM, Shen XM, Heidenreich F, Vincent A, et al. The spectrum of mutations causing end-plate acetylcholinesterase deficiency. *Ann Neurol* 2000; 47: 162-70.
61. Shapira M, Tur-Kaspa I, Bosgraaf L, Livni N, Grant AD, Grisaru D, et al. A transcription-activating polymorphism in the ACHE promoter associated with acute sensitivity to anti-acetylcholinesterases. *Hum Mol Genet* 2000; 9: 1273-81.
62. Soreq H, Seidman S. Acetylcholinesterase - new roles for an old actor. *Nat Rev Neurosci* 2001; 2: 294-302.
63. O'Brien KK, Saxby BK, Ballard CG, Grace J, Harrington F, Ford GA. Regulation of attention and response to therapy in dementia by butyrylcholinesterase. *Pharmacogenetics* 2003; 13: 231-9.
64. Holmes C, Ballard C, Lehmann D, David Smith A, Beaumont H, Day IN, et al. Rate of progression of cognitive decline in Alzheimer's disease: effect of butyrylcholinesterase K gene variation. *J Neurol Neurosurg Psychiatry* 2005; 76: 640-3.
65. Miller RD, Dennissen PA, van der Pol F, Agoston S, Booij LH, Crul JF. Potentiation of neostigmine and pyridostigmine by 4-aminopyridine in the rat. *J Pharm Pharmacol* 1978; 30: 699-702.
66. Miller RD, Booij LH, Agoston S, Crul JF. 4-Aminopyridine potentiates neostigmine and pyridostigmine in man. *Anesthesiology* 1979; 50: 416-20.
67. Foldes FF, Derry A. Protein binding of atracurium and other short-acting neuromuscular blocking agents and their interaction with human cholinesterases. *Br J Anaesth* 1983; 55 Suppl. 1: 31S-34S.
68. Kato M, Hashimoto Y, Horinouchi T, Ando T, Ito J, Yamanaka H. Inhibition of human plasma cholinesterase and erythrocyte acetylcholinesterase by nondepolarizing neuromuscular blocking agents. *J Anesth* 2000; 14: 30-4.
69. Kim KS, Lew SH, Cho HY, Cheong MA. Residual paralysis induced by either vecuronium or rocuronium after reversal with pyridostigmine. *Anesth Analg* 2002; 95: 1656-60.
70. Magorian TT, Lynam DP, Caldwell JE, Miller RD. Can early administration of neostigmine, in single or repeated doses, alter the course of neuromuscular recovery from a vecuronium-induced neuromuscular blockade? *Anesthesiology* 1990; 73: 410-4.
71. Weinbroum AA. Pathophysiological and clinical aspects of combat anticholinesterase poisoning. *Br Med Bull* 2005; 72: 119-33.
72. Li H, Schopfer LM, Nachon F, Froment MT, Masson P, Lockridge O. Aging pathways for organophosphate- inhibited human butyrylcholinesterase, including novel pathways for isomalathion, resolved by mass spectrometry. *Toxicol Sci* 2007; 100: 136-45.
73. Hsieh BH, Deng JF, Ger J, Tsai WJ. Acetylcholinesterase inhibition and the extrapyramidal syndrome: a review of the neurotoxicity of organophosphate. *Neurotoxicology* 2001; 22: 423-7.
74. Wilson IB. The interaction of tensilon and neostigmine with acetylcholinesterase. *Arch Int Pharmacodyn Ther* 1955; 104: 204-13.
75. Kitz RJ. The chemistry of anticholinesterase activity. *Acta Anaesthesiol Scand* 1964; 8: 199-218.
76. Wilson IB, Harrison MA, Ginsberg S. Carbamyl derivatives of acetylcholinesterase. *J Biol Chem* 1961; 238: 1498-500.
77. Barber HE, Calvey TN, Muir KT. The relationship between the pharmacokinetics, cholinesterase inhibition and facilitation of twitch tension of the quaternary ammonium anticholinesterase drugs, neostigmine, pyridostigmine, edrophonium and 3-hydroxyphenyltrimethylammonium. *Br J Pharmacol* 1979; 66: 525-30.
78. Bartkowski RR. Incomplete reversal of pancuronium neuromuscular blockade by neostigmine, pyridostigmine, and edrophonium. *Anesth Analg* 1987; 66: 594-8.
79. Deanna A, Scuka N. Time course of neostigmine: action on the endplate response. *Neuroscience* 1990; 118: 82-4.
80. Zwart R, van Kleef RG, Gotti C, Smulders CJ, Vijverberg HP. Competitive potentiation of acetylcholine effects on neuronal nicotinic receptors by acetylcholinesterase- inhibiting drugs. *J Neurochem* 2000; 75: 2492-500.
81. Militante J, Ma BW, Akk G, Steinbach JH. Activation and block of the adult muscle-type nicotinic receptor by physostigmine: single-channel studies. *Mol Pharmacol* 2008; 74: 764-76.
82. Akk G, Steinbach JH. Galanthamine activates muscle-type nicotinic acetylcholine receptors without binding to the acetylcholine-binding site. *J Neurosci* 2005; 25: 1992-2001.
83. Sherby SM, Eldefrawi AT, Albuquerque EX, Eldefrawi ME. Comparison of the actions of carbamate anticholinesterases on the nicotinic acetylcholine receptor. *Mol Pharmacol* 1985; 27: 343-8.
84. Goldhill DR, Wainwright AP, Stuart CS, Flynn PJ. Neostigmine after spontaneous recovery from neuromuscular blockade. Effect on depth of blockade monitored with train-of-four and tetanic stimuli. *Anaesthesia*. 1989; 44: 293-9.
85. Wachtel RE. Comparison of anticholinesterases and their effects on acetylcholine-activated ion channels. *Anesthesiology* 1990; 72:

- 496-503.
86. Braga MFM, Rowan EG, Harvey AL, Bowman WC. Prejunctional action of neostigmine on mouse neuromuscular preparations. *Br J Anaesth* 1993; 70: 405-10.
 87. Blaber LC. The mechanism of the facilitatory action of edrophonium in cat skeletal muscle. *Br J Pharmacol* 1972; 46: 498-507.
 88. Donati F, Ferguson A, Bevan DR. Twitch depression and train-of-four ratio after antagonism of pancuronium with edrophonium, neostigmine or pyridostigmine. *Anesth Analg* 1983; 62: 314-6.
 89. Fisher DM, Cronnelly R, Miller RD. Clinical pharmacology of edrophonium in infants and children. *Anesthesiology* 1984; 61: 428-33.
 90. Ponec RJ, Saunders MD, Kimmey MB. Neostigmine for the treatment of the acute colonic pseudo-obstruction. *N Engl J Med* 1999; 341: 137-41.
 91. Muñoz-Torrero D. Acetylcholinesterase inhibitors as disease-modifying therapies for Alzheimer's disease. *Curr Med Chem* 2008; 15: 2433-55.
 92. Russell WJ. The impact of Alzheimer's disease medication on muscle relaxants. *Anaesth Intensive Care* 2009; 37: 134-5.
 93. Buvanendran A, Kroin JS. Useful adjuvants for postoperative pain management. *Best Pract Res Clin Anaesthesiol* 2007; 21: 31-49.
 94. Lauretti GR, Reis MP. Postoperative analgesia and antiemetic efficacy after subarachnoid neostigmine in orthopedic surgery. *Reg Anesth* 1997; 22: 337-42.
 95. Hood DD, Eisenach JC, Tuttle R. Phase I safety assessment of intrathecal neostigmine methylsulfate in humans. *Anesthesiology* 1995; 82: 331-43.
 96. Kreis ME, Kasparek M, Zittel TT, Becker HD, Jehle EC. Neostigmine increases postoperative colonic motility in patients undergoing colorectal surgery. *Surgery* 2001; 130: 449-56.
 97. Bharucha AE, Low PA, Camilleri M, Burton D, Gehrking TL, Zinsmeister AR. Pilot study of pyridostigmine in constipated patients with autonomic neuropathy. *Clin Auton Res* 2008; 18: 194-202.
 98. Rosman AS, Chaparala G, Monga A, Spungen AM, Bauman WA, Korsten MA. Intramuscular neostigmine and glycopyrrolate safely accelerate bowel evacuation in patients with spinal cord injury and defecatory disorders. *Dig Dis Sci* 2008; 53: 2710-3.
 99. Mattei P, Rombeau LJ. Review of the pathophysiology and management of postoperative ileus. *World J Surg* 2006; 30: 1382-91.
 100. Caliskan E, Turkoz A, Sener M, Bozdogan N, Gulcan O, Turkoz R. A prospective randomized double-blind study to determine the effect of thoracic epidural neostigmine on postoperative ileus after abdominal aortic surgery. *Anesth Analg* 2008; 106: 959-64.
 101. Donati F, Bevan DR. Controlled succinylcholine infusion in a patient receiving echothiopate eye drops. *Can Anaesth Soc J* 1981; 28: 488-90.
 102. Cavallaro RJ, Krumperman LW, Kugler F. Effect of echothiopate therapy on the metabolism of succinylcholine in man. *Anesth Analg* 1968; 47: 570-74.
 103. Gesztes T. Prolonged apnoea after suxamethonium injection associated with eye drops containing an anticholinesterase agent. *Br J Anaesth* 1966; 38: 408-9.
 104. Pantuck EJ. Echothiopate iodide eye drops and prolonged response to suxamethonium. *Br J Anaesth* 1966; 38: 406-7.
 105. Blobner M, Mann R. Anästhesie bei Patienten mit Myasthenia gravis. *Anaesthesist* 2001; 50: 484-93.
 106. Wittbrodt ET. Drugs and myasthenia gravis: an update. *Arch Intern Med* 1997; 157: 399-408.
 107. Cohen S, Hunter CW, Yanni B, Striker P, Hijazi RH. Central anticholinergic syndrome strikes again. *J Clin Anesth* 2006; 18: 399-400.
 108. Funk W, Hollnberger H, Geroldinger J. Physostigmine and anaesthesia emergence delirium in preschool children: a randomized blinded trial. *Eur J Anaesthesiol* 2008; 25: 37-42.
 109. Moller JT, Cluitmans P, Rasmussen LS, Houx P, Rasmussen H, Canet J, et al. Long-term postoperative cognitive dysfunction in the elderly ISPOCD1 study: ISPOCD1 investigators. International study of postoperative cognitive dysfunction. *Lancet* 1998; 351: 857-61.
 110. Yildizeli B, Ozyurtkan MO, Batirel HF, Kuscu K, Bekiroglu N, Yuksel M. Factors associated with postoperative delirium after thoracic surgery. *Ann Thorac Surg* 2005; 79: 1004-9.
 111. Praticò C, Quattrone D, Lucanto T, Amato A, Penna O, Roscitano C, et al. Drugs of anesthesia acting on central cholinergic system may cause post-operative cognitive dysfunction and delirium. *Med Hypotheses* 2005; 65: 972-82.
 112. Senne I, Zourelidis C, Irnich D, Kurz M, Hummel T, Zwissel B. Central anticholinergic syndrome and apnea after general anaesthesia. A rare manifestation of the central anticholinergic syndrome. *Anaesthesist* 2003; 52: 608-11.
 113. Brown DV, Heller F, Barkin R. Anticholinergic syndrome after anesthesia: a case report and review. *Am J Ther* 2004; 11: 144-53.
 114. Schultz U, Idelberger R, Rossaint R, Buhre W. Central anticholinergic syndrome in a child undergoing circumcision. *Acta Anaesthesiol Scand* 2002; 46: 224-6.
 115. Katsanoulas K, Papaioannou A, Fraidakis O, Michaloudis D. Undiagnosed central anticholinergic syndrome may lead to dangerous complications. *Eur J Anaesthesiol* 1999; 16: 803-9.
 116. Kabatnik M, Heist M, Beiderlinden K, Peters J. Hepatic encephalopathy--a physostigmine-reactive central anticholinergic syndrome? *Eur J Anaesthesiol* 1999; 16: 140-2.
 117. Martin B, Howell PR. Physostigmine: going ... going ... gone? Two cases of central anticholinergic syndrome following anaesthesia and its treatment with physostigmine. *Eur J Anaesthesiol* 1997; 14: 467-70.

118. Caldwell JE, Robertson EN, Baird WLM. Antagonism of vecuronium and atracurium: comparison of neostigmine and edrophonium administered at 5% twitch height recovery. *Br J Anaesth* 1987; 59: 478-81.
119. Bartkowski RR. Incomplete reversal of pancuronium neuromuscular blockade by neostigmine, pyridostigmine, and edrophonium. *Anesth Analg* 1987; 66: 594-8.
120. Rupp SM, McChristian JW, Miller RD, Taboada JA, Cronnelly R. Neostigmine and edrophonium antagonism of varying intensity neuromuscular blockade induced by atracurium, pancuronium, or vecuronium. *Anesthesiology* 1986; 64: 711-7.
121. Katz RL. Clinical neuromuscular pharmacology of pancuronium. *Anesthesiology* 1971; 34: 550-6.
122. Beemer GH, Bjorksten AR, Dawson PJ, Dawson RJ, Heenan PJ, Robertson BA. Determinants of the reversal time of competitive neuromuscular block by anticholinesterases. *Br J Anaesth* 1991; 66: 469-75.
123. Hennart D, d'Hollander A, Plasman C, De Jonckheere M. Importance of the level of paralysis recovery for a rapid antagonism of atracurium neuromuscular blockade with moderate doses of edrophonium. *Anesthesiology* 1986; 64: 384-7.
124. Engbaek J, Ording H, Ostergaard D, Viby-Mogensen J. Edrophonium and neostigmine for reversal of the neuromuscular blocking effect of vecuronium. *Acta Anaesthesiol Scand* 1985; 29: 544-6.
125. Donati F, Smith CE, Bevan DR. Dose-response relationships for edrophonium and neostigmine as antagonists of moderate and profound atracurium blockade. *Anesth Analg* 1989; 68: 13-9.
126. Jones JE, Hunter JM, Utting JE. Use of neostigmine in the antagonism of residual neuromuscular blockade produced by vecuronium. *Br J Anaesth* 1987; 59: 1454-8.
127. Beemer GH, Goonetilleke PH, Bjorksten AR. The maximum depth of an atracurium neuromuscular block antagonized by edrophonium to effect adequate recovery. *Anesthesiology* 1995; 82: 852-8.
128. Kirkegaard-Nielsen H, Helbo-Hansen HS, Lindholm P, Severinsen IK, Pedersen HS. Anthropometric variables as predictors for duration of action of atracurium-induced neuromuscular block. *Anesth Analg* 1996; 83: 1076-80.
129. Magorian TT, Lynam DP, Caldwell JE, Miller RD. Can early administration of neostigmine, in single or repeated doses, alter the course of neuromuscular recovery from a vecuronium-induced neuromuscular blockade? *Anesthesiology* 1990; 73: 410-4.
130. Kirkegaard-Nielsen H, Helbo-Hansen HS, Lindholm P, Severinsen IK, Billow K. Time to peak effect of neostigmine at antagonism of atracurium- or vecuronium-induced neuromuscular block. *J Clin Anesth* 1995; 7: 635-9.
131. Lessard MR, Trépanier CA, Rouillard JF. Neostigmine requirements for reversal of neuromuscular blockade following an infusion of mivacurium. *Can J Anaesth* 1997; 44: 836-42.
132. Bevan DR. Reversal of pancuronium with edrophonium. *Anaesthesia* 1979; 34: 614-9.
133. Rupp SM, McChristian JW, Miller RD, Taboada JA, Cronnelly R. Neostigmine and edrophonium antagonism of varying intensity neuromuscular blockade induced by atracurium, pancuronium, or vecuronium. *Anesthesiology* 1986; 64: 711-7.
134. Kopman AF. Recovery times following edrophonium and neostigmine reversal of pancuronium, atracurium, and vecuronium steady-state infusions. *Anesthesiology* 1986; 65: 572-8.
135. Kirkegaard-Nielsen H, Helbo-Hansen HS, Lindholm P, Severinsen IK, Bülow K. Time to peak effect of neostigmine at antagonism of atracurium- or vecuronium-induced neuromuscular block. *J Clin Anesth* 1995; 7: 635-9.
136. Caldwell JE, Robertson EN, Baird WL. Antagonism of vecuronium and atracurium: comparison of neostigmine and edrophonium administered at 5% twitch height recovery. *Br J Anaesth* 1987; 59: 478-81.
137. Jones JE, Parker CJ, Hunter JM. Antagonism of blockade produced by atracurium or vecuronium with low doses of neostigmine. *Br J Anaesth* 1988; 61: 560-4.
138. Szenohradszky J, Lau M, Brown R, Sharma ML, Fisher DM. The effect of neostigmine on twitch tension and muscle relaxant concentration during infusion of mivacurium or vecuronium. *Anesthesiology* 1995; 83: 83-7.
139. Fogdall RP, Miller RD. Antagonism of d-tubocurarine- and pancuronium-induced neuromuscular blockades by pyridostigmine in man. *Anesthesiology* 1973; 39: 504-9.
140. Ravin MB. Pyridostigmine as an antagonist of d-tubocurarine-induced and pancuronium-induced neuromuscular blockade. *Anesth Analg* 1975; 55: 317-21.
141. Kopman AF. Recovery times following edrophonium and neostigmine reversal of pancuronium, atracurium, and vecuronium steady-state infusions. *Anesthesiology* 1986; 65: 572-8.
142. Symington MJ, Mirakhur RK, Kumar N. Neostigmine but not edrophonium prolongs the action of mivacurium. *Can J Anaesth* 1996; 43: 1220-3.
143. Hart PS, Wright PMC, Brown R, Lau M, Sharma M, Miller RD, et al. Edrophonium increases mivacurium concentrations during constant mivacurium infusion, and large doses minimally antagonize paralysis. *Anesthesiology* 1995; 82: 912-8.
144. Szenohradszky J, Lau M, Brown R, Sharma ML, Fisher DM. The effect of neostigmine on twitch tension and muscle relaxant concentration during infusion of mivacurium or vecuronium. *Anesthesiology* 1995; 83: 83-7.
145. Savarese JJ, Ali HH, Basta SJ, Embree PB, Scott RPF, Sunder N, Weakly JN, Wastila WB, EL-Sayad HA. The clinical neuromuscular pharmacology of mivacurium chloride (BW B1090U). *Anesthesiology* 1988; 68: 723-32.
146. Connolly FM, Mirakhur RK, Loan PB, McCoy EP, Symington M, Kumar N. Antagonism of mivacurium block with edrophonium from various degrees of spontaneous recovery. *Br J Anaesth* 1995; 74: 229-30.

147. Devcic A, Munshi CA, Gandhi SK, Kampine JP. Antagonism of mivacurium neuromuscular block: neostigmine versus edrophonium. *Anesth Analg* 1995; 81: 1005-9.
148. Bartunek A, Gilly H, Huemer G, Yildiz S, Schramm W, Lackner FX, et al. [Neostigmine and edrophonium. Antagonism of profound and shallow mivacurium blockade]. *Anaesthetist* 1997; 46: 96-100.
149. Fleming NW, Lewis BK. Cholinesterase inhibitors do not prolong neuromuscular block produced by mivacurium. *Br J Anaesth* 1994; 73: 241-3.
150. Motamed C, Kirov K, Lieutaud T, Duvaldestin P. The mechanism of pancuronium potentiation of mivacurium block: use of the isolated-arm technique. *Anesth Analg* 2000; 91: 732-5.
151. Motamed C, Menad R, Farinotti R, Kirov K, Combes X, Bouleau D, et al. Potentiation of mivacurium blockade by low dose of pancuronium: a pharmacokinetic study. *Anesthesiology* 2003; 98: 1057-62.
152. Motamed C, Kirov K, Combes X, Dhonneur G, Duvaldestin P. Effect of metoclopramide on mivacurium-induced neuromuscular block. *Acta Anaesthesiol Scand* 2002; 46: 214-6.
153. Tunek A, Svensson LA. Bambuterol, a carbamate ester prodrug of terbutaline, as inhibitor of cholinesterases in human blood. *Drug Metab Dispos* 1988; 16: 759-64.
154. Robertson GS. Serum protein and cholinesterase changes in association with contraceptive pills. *Lancet* 1967; 1: 232-5.
155. Miller RD, Van Nyhuis LS, Eger EI 2nd, Vitez TS, Way WL. Comparative times to peak effect and durations of action of neostigmine and pyridostigmine. *Anesthesiology* 1974; 41: 27-33.
156. Ferguson A, Egerszegi P, Bevan DR. Neostigmine, pyridostigmine, and edrophonium as antagonists of pancuronium. *Anesthesiology* 1980; 53: 390-4.
157. Mirakhur RK, Gibson FM, Lavery GG. Antagonism of vecuronium-induced neuromuscular blockade with edrophonium or neostigmine. *Br J Anaesth* 1987; 59: 473-7.
158. Caldwell JE, Robertson EN, Baird WLM. Antagonism of vecuronium and atracurium: comparison of neostigmine and edrophonium administered at 5% twith height revocery. *Br J Anaesth* 1997; 59: 478-81.
159. Morris RB, Miller RD. Edrophonium: duration of action and atropine requirement in humans during halothane anesthesia. *Anesthesiology* 1982; 57: 261-6.
160. Schuh FT. [On the molecular mechanism of action of galanthamine, an antagonist of nondepolarizing muscle relaxants]. *Anesthesist* 1976; 25: 444-8.
161. Mashkovskii MD. [Effects of galanthamine on the acetylcholine sensitivity of skeletal musculature]. *Farmakol Toksikol* 1955; 18: 21-7 (Chem Abs 50, 9626c, 1956).
162. Irwin RL, Smith HJ. The activity of galanthamine and related compounds on muscle. *Arch Int Pharmacodyn Ther* 1960; 127: 314-30.
163. Cheymol J, Boissier JR, Bourillet F, Fichelle-Pagny J, Roth-Arveiller M. Activite neuromusculaire de la galanthamine, anticholinesterasique nature]. *Ann Pharm Fr* 1964; 22: 41-8.
164. Baraka A, Cozanitis D. Galanthamine versus neostigmine for reversal of nondepolarizing neuromuscular block in man. *Anesth Analg* 1973; 52: 832-6.
165. De Angelis J, Walts LF. Comparison of galanthamine with neostigmine for reversal of d-tubocurarine neuromuscular blockade in man. *Anesth Analg* 1972; 51: 196-9.
166. Karis JH, Nastuk WL, Katz RL. The action of tacrine on neuromuscular transmission: a comparison with hexafluorenium. *Br J Anaesth* 1966; 38: 762-74.
167. Salmenperä M, Nilsson E. Comparison of physostigmine and neostigmine for antagonism of neuromuscular block. *Acta Anaesthesiol Scand* 1981; 25: 387-90.
168. Baraka A. Antagonism of neuromuscular block by physostigmine in man. *Br J Anaesth* 1978; 50: 1075-7.
169. Manoguerra AS, Steiner RW. Prolonged neuromuscular blockade after administration of physostigmine and succinylcholine. *Clin Toxicol* 1981; 18: 803-5.
170. Biessels PT, Houwertjes MC, Agoston S, Horn AS. Interaction of 2,4-diaminopyridine with cholinesterase inhibitors. *Arch Int Pharmacodyn Ther* 1988; 293: 228-35.
171. Treffers R, Frankhuyzen AL, Booij LH. Effects of neostigmine, edrophonium, 4-aminopyridine and their combinations. *Acta Anaesthesiol Belg* 1988; 39: 55-8.
172. Soni N, Kamp P. 4-Aminopyridine. A review. *Anesth Intens Care* 1982; 10: 120-6.
173. Glover WE. The aminopyridines. *Gen Pharmacol* 1982; 13: 259-85.
174. Booij LHDJ, van der Pol F, Crul JF, Miller RD. Antagonism of Org NC45 neuromuscular blockade by neostigmine, pyridostigmine and 4-aminopyridine. *Anesth Analg* 1980; 59: 31-4.
175. Miller RD, Booij LH, Agoston S, Crul JF. 4-Aminopyridine potentiates neostigmine and pyridostigmine in man. *Anesthesiology* 1979; 50: 416-20.
176. Miller RD, Denissen PA, van der Pol F, Agoston S, Booij LH, Crul JF. Potentiation of neostigmine and pyridostigmine by 4-aminopyridine in the rat. *J Pharm Pharmacol* 1978; 30: 699-702.
177. Tierney PC, Kim YI, Johns TR. Synergistic interaction of 4-aminopyridine with neostigmine at the neuromuscular junction. *Eur J*

- Pharmacol 1985; 115: 241-7.
178. Stovner J, Stadskleiv K. Suxamethonium apnoea terminated with commercial serum cholinesterase. *Acta Anaesthesiol Scand* 1976; 20: 211-5.
179. Scholler KL, Goedde HW, Benkmann H-G. The use of serum cholinesterase in succinylcholine apnoea. *Can Anaesth Soc J* 1977; 24: 396-400.
180. Schuh FT. Serum cholinesterase: Effect on the action of suxamethonium following administration to a patient with cholinesterase deficiency. *Br J Anaesth* 1977; 49: 269-72.
181. Benzer A, Luz G, Oswald E, Schmoigl C, Menardi G. Succinylcholine-induced prolonged apnea in a 3-week-old newborn: Treatment with human plasma cholinesterase. *Anesth Analg* 1992; 74: 137-8.
182. Naguib M, El-Gammal M, Daoud W, Ammar A, Moukhtar H, Turkistani A. Human plasma cholinesterase for antagonism of prolonged mivacurium-induced neuromuscular blockade. *Anesthesiology* 1995; 82: 1288-92.
183. Naguib M, Daoud W, el-Gammal M, Ammar A, Turkistani A, Selim M, et al. Enzymatic antagonism of mivacurium-induced neuromuscular blockade by human plasma cholinesterase. *Anesthesiology* 1995; 83: 694-701.
184. Geyer BC, Fletcher SP, Griffin TA, Lopker MJ, Soreq H, Mor TS. Translational control of recombinant human acetylcholinesterase accumulation in plants. *BMC Biotechnol* 2007 May 30; 7: 27.
185. Huang YJ, Huang Y, Baldassarre H, Wang B, Lazaris A, Leduc M, et al. Recombinant human butyrylcholinesterase from milk of transgenic animals to protect against organophosphate poisoning. *Proc Natl Acad Sci USA* 2007; 104: 13603-8.
186. Huang YJ, Lundy PM, Lazaris A, Huang Y, Baldassarre H, Wang B, et al. Substantially improved pharmacokinetics of recombinant human butyrylcholinesterase by fusion to human serum albumin. *BMC Biotechnol* 2008; 8: 50.
187. Saxena A, Sun W, Dabisch PA, Hulet SW, Hastings NB, Jakubowski EM, et al. Efficacy of human serum butyrylcholinesterase against sarin vapor. *Chem Biol Interact* 2008; 175: 267-72.
188. Baraka A. Irreversible tubocurarine neuromuscular block in the human. *Br J Anaesth* 1967; 39: 891-4.
189. Brooks DK, Feldman SA. Metabolic acidosis. A new approach to 'neostigmine resistant curarisation'. *Anaesthesia* 1962; 17: 161-9.
190. Bush GH, Baraka A. Factors affecting the termination of curarization in the human subject. *Br J Anaesth* 1964; 36: 356-62.
191. Miller RD, Van Nyhuis LS, Eger EI 2nd, Way WL. The effect of acid-base balance on neostigmine antagonism of d-tubocurarine-induced neuromuscular blockade. *Anesthesiology* 1975; 42: 377-83.
192. Miller RD, Roderick LL. Acid-base balance and neostigmine antagonism of pancuronium neuromuscular blockade. *Br J Anaesth* 1978; 50: 317-24.
193. Brooks DK, Feldman SA. Metabolic acidosis. A new approach to 'neostigmine resistant curarisation'. *Anaesthesia* 1962; 17: 161-9.
194. Brooks DK, Feldman SA. Metabolic acidosis. A new approach to "neostigmine resistant curarisation". 1962. *Anaesthesia* 1995; 50: 713-8.
195. Baurain MJ, d'Hollander AA, Melot C, Dernovoi BS, Barvais L. Effects of residual concentrations of isoflurane on the reversal of vecuronium-induced neuromuscular blockade. *Anesthesiology* 1991; 74: 474-8.
196. Morita T, Tsukagoshi H, Sugaya T, Saito S, Sato H, Fujita T. Inadequate antagonism of vecuronium induced neuromuscular block during sevoflurane or isoflurane anesthesia. *Anesth Analg* 1995; 80: 1175-80.
197. Morita T, Kurosaki D, Tsukagoshi H, Shimada H, Sato H, Goto F. Factors affecting neostigmine reversal of vecuronium block during sevoflurane anaesthesia. *Anaesthesia* 1997; 52: 538-43.
198. Reid JE, Breslin DS, Mirakhur RK, Hayes AH. Neostigmine antagonism of rocuronium block during anesthesia with sevoflurane, isoflurane or propofol. *Can J Anaesth* 2001; 48: 351-5.
199. Delisle S, Bevan DR. Impaired neostigmine antagonism of pancuronium during enflurane anaesthesia in man. *Br J Anaesth* 1982; 84: 441-4.
200. Dernovoi B, Agoston S, Barvais L, Baurain M, Lefebvre R, d'Hollander A. Neostigmine antagonism of vecuronium paralysis during fentanyl, halothane, isoflurane, and enflurane anesthesia. *Anesthesiology* 1987; 66: 698-701.
201. Oris B, Crul JF, Vandermeersch E, Van Aken H, Van Egmond J, Sabbe MB. Muscle paralysis by rocuronium during halothane, enflurane, isoflurane, and total intravenous anesthesia. *Anesth Analg* 1993; 77: 570-3.
202. Shanks CA, Fragen RJ, Ling D. Continuous intravenous infusion of rocuronium (ORG 9426) in patients receiving balanced, enflurane or isoflurane anesthesia. *Anesthesiology* 1993; 78: 649-51.
203. Morita T, Kurosaki D, Tsukagoshi H, Sugaya T, Saito S, Sato H, et al. Sevoflurane and isoflurane impair edrophonium reversal of vecuronium-induced neuromuscular block. *Can J Anaesth* 1996; 43: 799-805.
204. Sutcliffe DG, Murphy CM, Maslow A, Uppington J, Shorten GD. A comparison of antagonism of rocuronium-induced neuromuscular blockade during sevoflurane and isoflurane anaesthesia. *Anesthesia* 2000; 55: 960-4.
205. Adamson RH, Marshall FN, Long JP. Neuromuscular blocking properties of various polypeptide antibiotics. *Proc Soc Exp Biol Med* 1960; 105: 494-7.
206. Naiman JG, Martin JD Jr. Some aspects of neuromuscular blockade by polymyxin Br J Surg Res 1967; 7: 199-206.
207. Van Nyhuis LS, Miller RD, Fogdall RP. The interaction between d-tubocurarine, pancuronium, polymyxin B, and neostigmine on neuromuscular function. *Anesth Analg* 1976; 55: 224-8.

208. Hasfurther DL, Bailey PL. Failure of neuromuscular blockade reversal after rocuronium in a patient who received oral neomycin. *Can J Anaesth* 1996; 43: 617-20.
209. Renna G, Siro-Brigiani G, Cuomo V. Comparative evaluation of the neuromuscular blocking activity of three new aminoglycoside antibiotics in rats. *Toxicol Lett* 1981; 9: 107-12.
210. Lee SI, Lee JH, Lee SC, Lee JM, Lee JH. Calcium and neostigmine antagonize gentamicin, but augment clindamycin-induced tetanic fade in rat phrenic nerve-hemidiaphragm preparations. *J Anesth* 2008; 22: 385-90.
211. Bradley RJ. Reversal of organophosphate-induced muscle block by neomycin. *Brain Res* 1986; 381: 397-400.
212. Sobek V. The effect of calcium, neostigmine and 4-aminopyridine upon respiratory arrest and depression of cardiovascular functions after aminoglycosidic antibiotics. *Arzneimittelforschung* 1982; 32: 222-4.
213. al Ahdal O, Bevan DR. Clindamycin-induced neuromuscular blockade. *Can J Anaesth* 1995; 42: 614-7.
214. Booij LH, Miller RD, Crul JF. Neostigmine and 4-aminopyridine antagonism of lincomycin-pancuronium neuromuscular blockade in man. *Anesth Analg* 1978; 57: 316-21.
215. Singh YN, Harvey AL, Marshall IG. Antibiotic-induced paralysis of the mouse phrenic nerve-hemidiaphragm preparation, and reversibility by calcium and by neostigmine. *Anesthesiology* 1978; 48: 418-24.
216. Hennis PJ, Cronnelly R, Sharma M, Fisher DM, Miller RD. Metabolites of neostigmine and pyridostigmine do not contribute to antagonism of neuromuscular blockade in the dog. *Anesthesiology* 1984; 61: 534-9.
217. Cronnelly R, Stanski DR, Miller RD, Sheiner LB, Sohn YJ. Renal function and the pharmacokinetics of neostigmine in anesthetized man. *Anesthesiology* 1979; 51: 222-6.
218. Williams AR, Bailey M, Joye T, Burt N. Marked prolongation of the succinylcholine effect two hours after neostigmine reversal of neuromuscular blockade in a patient with chronic renal insufficiency. *South Med J* 1999; 92: 77-9.
219. Cronnelly R, Stanski DR, Miller RD, Sheiner LB. Pyridostigmine kinetics with and without renal function. *Clin Pharmacol Ther* 1980; 28: 78-81.
220. Morris RB, Cronnelly R, Miller RD, Stanski DR, Fahey MR. Pharmacokinetics of edrophonium in anephric and renal transplant patients. *Br J Anaesth* 1981; 53: 1311-4.
221. Burdfield PA, Calvey TN. Plasma clearance of neostigmine and pyridostigmine in rats with ligated renal pedicles. *Eur J Pharmacol* 1973; 24: 252-5.
222. Bevan DR, Archer D, Donati F, Ferguson A, Higgs BD. Antagonism of pancuronium in renal failure: no recurrarization. *Br J Anaesth* 1982; 54: 63-8.
223. Dhonneur G, Rebaine C, Slavov V, Ruggier R, De Chabry V, Duvaldestin P. Neostigmine reversal of vecuronium neuromuscular block and the influence of renal failure. *Anesth Analg* 1996; 82: 134-8.
224. Fisher DM, Cronnelly R, Miller RD, Sharma M. The neuromuscular pharmacology of neostigmine in infants and children. *Anesthesiology* 1983; 59: 220-5.
225. Abdulatif M, El-Sanabary M. Edrophonium antagonism of cisatracurium-induced neuromuscular block: dose requirements in children and adults. *Anaesth Intensive Care* 2001; 29: 364-70.
226. Fisher DM, Cronnelly R, Sharma M, Miller RD. Clinical pharmacology of edrophonium in infants and children. *Anesthesiology* 1984; 61: 428-33.
227. Debaene B, Meistelman C, d'Hollander A. Recovery from vecuronium neuromuscular blockade following neostigmine administration in infants, children, and adults during halothane anesthesia. *Anesthesiology* 1989; 71: 840-4.
228. Young WL, Matteo RS, Ornstein E. Duration of action of neostigmine and pyridostigmine in the elderly. *Anesth Analg* 1988; 67: 775-8.
229. Bevan DR, Donati F, Kopman AK. Reversal of neuromuscular blockade. *Anesthesiology* 1992; 77: 785-805.
230. Stone JG, Matteo RS, Ornstein E, Schwartz AE, Ostapkovich N, Jamdar SC, et al. Aging alters the pharmacokinetics of pyridostigmine. *Anesth Analg* 1995; 81: 773-6.
231. Fisher DM, Cronnelly R, Miller RD. The neuromuscular pharmacology of neostigmine in infants and children. *Anesthesiology* 1983; 59: 220-5.
232. Matteo RS, Young WL, Ornstein E, Schwartz AE, Silverberg PA, Diaz J. Pharmacokinetics and pharmacodynamics of edrophonium in elderly surgical patients. *Anesth Analg* 1990; 71: 334-9.
233. Young WL, Matteo RS, Ornstein E. Duration of action of neostigmine and pyridostigmine in the elderly. *Anesth Analg* 1988; 67: 775-8.
234. McCarthy GJ, Mirakhur RK, Maddineni VR, McCoy EP. Dose-responses for edrophonium during antagonism of vecuronium block in young and older adult patients. *Anesthesia* 1995; 50: 503-6.
235. Kirkegaard-Nielsen H, Helbo-Hansen HS, Lindholm P, Severinsen IK, Pedersen HS. Anthropometric variables as predictors for duration of action of atracurium-induced neuromuscular block. *Anesth Analg* 1996; 83: 1076-80.
236. Kirkegaard-Nielsen H, Lindholm P, Petersen HS, Severinsen IK. Antagonism of atracurium-induced block in obese patients. *Can J Anaesth* 1998; 45: 39-41.
237. Suzuki T, Masaki G, Ogawa S. Neostigmine-induced reversal of vecuronium in normal weight, overweight and obese female patients.

- Br J Anaesth 2006; 97: 160-3.
238. Roufogalis BD, Quist EE, Wickson VM. Effect of ligands on a discontinuous temperature dependence of the decarbamylation reaction of erythrocyte acetylcholinesterase. *Biochim Biophys Acta* 1973; 321: 536-45.
239. Heier T, Clough D, Wright PM, Sharma ML, Sessler DI, Caldwell JE. The influence of mild hypothermia on the pharmacokinetics and time course of action of neostigmine in anesthetized volunteers. *Anesthesiology* 2002; 97: 90-5.
240. Miller RD, Roderick LL. Pancuronium-induced neuromuscular blockade, and its antagonism by neostigmine, at 29, 37, and 41°C. *Anesthesiology* 1977; 46: 333-5.
241. Miller RD, Van Nyhuis LS, Eger EI. The effect of temperature on a d-tubocurarine neuromuscular blockade and its antagonism by neostigmine. *J Pharmacol Exp Ther* 1975; 195: 237-41.
242. Motamed C, Donati F. Intubating conditions and blockade after mivacurium, rocuronium and their combination in young and elderly adults. *Can J Anaesth* 2000; 47: 225-31.
243. Breslin DS, Jiao K, Habib AS, Schultz J, Gan TJ. Pharmacodynamic interactions between cisatracurium and rocuronium. *Anesth Analg* 2004; 98: 107-10.
244. Naguib M, Samarkandi AH, Bakhames HS, Magboul MA, el-Bakry AK. Comparative potency of steroid neuromuscular blocking drugs and isobolographic analysis of the interaction between rocuronium and other aminosteroids. *Br J Anaesth* 1995; 75: 37-42.
245. Gyermek L. Clinical pharmacology of the reversal of neuromuscular block. *Int J Clin Pharmacol Biopharm* 1977; 15: 356-62.
246. Gyermek L. Clinical studies on the reversal of the neuromuscular blockade produced by pancuronium bromide, the effects of glycycycline and pyridostigmine. *Curr Ther Res* 1975; 18: 377-86.
247. Gyermek L, Cantley EM, Lee C. Antagonism of pancuronium- and pipecuronium-induced neuromuscular block. *Br J Anaesth* 1995; 74: 410-4.
248. Breen PJ, Doherty WG, Donati F, Bevan DR. The potencies of edrophonium and neostigmine as antagonists of pancuronium. *Anesthesia* 1985; 40: 844-7.
249. McCoy EP, Mirakhur RK. Comparison of the effects of neostigmine and edrophonium on the duration of action of suxamethonium. *Acta Anaesthesiol Scand* 1995; 39: 744-7.
250. Mirakhur RK, Lavery TD, Briggs LP, Clarke RSJ. Effect of neostigmine and pyridostigmine on serum cholinesterase activity. *Can Anaesth Soc J* 1982; 29: 55-8.
251. Devcic A, Munshi CA, Gandhi SK, Kampine JP. Antagonism of mivacurium neuromuscular block: neostigmine versus edrophonium. *Anesth Analg* 1995; 81: 1005-9.
252. Valdighi JB, Fleming NW, Smith BK, Baker GL, White DA. Effects of cholinesterase inhibitors on the neuromuscular blocking action of suxamethonium. *Br J Anaesth* 1994; 72: 237-9.
253. Naguib M, Selim M, Bakhames HS, Samarkandi AH, Turkistani A. Enzymatic versus pharmacologic antagonism of profound mivacurium-induced neuromuscular blockade. *Anesthesiology* 1996; 84: 1051-9.
254. Williams AR, Bailey M, Joye T, Burt N. Marked prolongation of the succinylcholine effect two hours after neostigmine reversal of neuromuscular blockade in a patient with chronic renal insufficiency. *South Med J* 1999; 92: 77-9.
255. Fleming NW, Macres S, Antognini JF, Vengco J. Neuromuscular blocking action of suxamethonium after antagonism of vecuronium by edrophonium, pyridostigmine or neostigmine. *Br J Anaesth* 1996; 77: 492-5.
256. Ramirez JG, Sprung J, Keegan MT, Hall BA, Bourke DL. Neostigmine-induced prolonged neuromuscular blockade in a patient with atypical pseudocholinesterase. *J Clin Anesth* 2005; 17: 221-324.
257. Hirst GR, Karandikar SS, Brown G, Slowey H, Beynon J. Colonic anastomotic disruption in the immediate postoperative period. *Int J Colorectal Dis* 2004; 19: 281-2.
258. Sener EB, Ustun E, Kocamanoglu S, Tur A. Prolonged apnea following succinylcholine administration in undiagnosed acute organophosphate poisoning. *Acta Anaesthesiol Scand* 2002; 46: 1046-8.
259. Pellegrini JE, Baker AB, Fontenot DJ, Cardenas AF. The effect of oral pyridostigmine bromide nerve agent prophylaxis on return of twitch height in persons receiving succinylcholine. *Mil Med* 2000; 165: 252-5.
260. Krasowski MD, McGehee DS, Moss J. Natural inhibitors of cholinesterases: implications for adverse drug reactions. *Can J Anaesth* 1997; 44: 525-34.
261. Triantafillou AN, Tsueda K, Berg J, Wieman TJ. Refractory bradycardia after reversal of muscle relaxant in a diabetic with vagal neuropathy. *Anesth Analg* 1986; 65: 1237-41.
262. Macintosh RR. Death Following Injection of Neostigmine. *Brit Med J* 1949; 1: 852.
263. Clutton-Brock JJ. Death Following neostigmine. *Brit Med J* 1949; 1: 1007.
264. Hill M. Death after neostigmine Injection. *Br Med J* 1949; 2: 601.
265. Beebe DS, Shumway SJ, Maddock R. Sinus arrest after intravenous neostigmine in two heart transplant recipients. *Anesth Analg* 1994; 78: 779-782.
266. Bjerer RJ, Mangione MP. Asystole after intravenous neostigmine in a heart transplant recipient. *Can J Anaesth* 2001; 48: 305-7.
267. Sawasdiwipachai P, Laussen PC, McGowan FX, Smoot L, Casta A. Cardiac arrest after neuromuscular blockade reversal in a heart transplant infant. *Anesthesiology* 2007; 107: 663-5.

268. Backman SB, Fox GS, Stein RD, Ralley FE. Neostigmine decreases heart rate in heart transplant patients. *Can J Anaesth* 1996; 43: 373-8.
269. Gottlieb JD, Sweet RB. The antagonism of curare: the cardiac effects of atropine and neostigmine. *Can Anaesth Soc J* 1963; 10: 114-21.
270. Baraka A. Safe reversal. 1. Atropine followed by neostigmine. An electrocardiographic study. *Br J Anaesth* 1968; 40: 27-9.
271. Ovassapian A. Effects of administration of atropine and neostigmine in man. *Anesth Analg* 1969; 48: 219-23.
272. Salem MR, Ylagan LB, Angel JJ, Vedam VS, Collins VJ. Reversal of curarization with atropine-neostigmine mixture in patients with congenital cardiac disease. *Br J Anaesth* 1970; 42: 991-8.
273. Ramamurthy S, Shaker MH, Winnie AP. Glycopyrrolate as a substitute for atropine in neostigmine reversal of muscle relaxant drugs. *Can Anaesth Soc J* 1972; 19: 399-411.
274. Mirakhur RK, Briggs LP, Clarke RS, Dundee JW, Johnston HM. Comparison of atropine and glycopyrrolate in a mixture with pyridostigmine for the antagonism of neuromuscular block. *Br J Anaesth* 1981; 53: 1315-20.
275. van Vlymen JM, Parlow JL. The effects of reversal of neuromuscular blockade on autonomic control in the perioperative period. *Anesth Analg* 1997; 84: 148-54.
276. Saarnivaara L, Simola M. Effects of four anticholinesterase-anticholinergic combinations and tracheal extubation on QTc interval of the ECG, heart rate and arterial pressure. *Acta Anaesthesiol Scand* 1998; 42: 460-3.
277. Webb MD. Type I second-degree AV block after neostigmine administration in a child with renal failure. *Anesth Prog* 1995; 42: 21-2.
278. Kido K, Mizuta K, Mizuta F, Yasuda M, Igari T, Takahashi M. Coronary vasospasm during the reversal of neuromuscular block using neostigmine. *Acta Anaesthesiol Scand* 2005; 49: 1395-6.
279. Hazizaj A, Hatija A. Bronchospasm caused by neostigmine. *Eur J Anaesthesiol* 2006; 23: 85-6.
280. Radulovic M, Spungen AM, Wecht JM, Korsten MA, Schilero GJ, Bauman WA, et al. Effects of neostigmine and glycopyrrolate on pulmonary resistance in spinal cord injury. *J Rehabil Res Dev* 2004; 41: 53-8.
281. Eikermann M, Fassbender P, Malhotra A, Takahashi M, Kubo S, Jordan AS, et al. Unwarranted administration of acetylcholinesterase inhibitors can impair genioglossus and diaphragm muscle function. *Anesthesiology* 2007; 107: 621-9.
282. Modell HI. Influence of anticholinesterase on distribution of ventilation and gas exchange. *Pharmacol Biochem Behav* 1991; 40: 17-20.
283. Caldwell RW, Lowensohn HS, Chryssanthis MA, Nash CB. Interactions of pyridostigmine with cardiopulmonary systems and their relationships to plasma cholinesterase activity. *Fundam Appl Toxicol* 1989; 12: 432-41.
284. Feldt-Rasmussen BF, Gefke K, Mosbech H, Hanel HK. Effect of a mixture of pyridostigmine and atropine on forced expiratory volume (FEV1), and serum cholinesterase activity in normal subjects. *Br J Anaesth* 1985; 57: 204-7.
285. Mollema R, Spijkstra JJ, Polderman KH, Gelissen HP, Girbes AR. Perforation of the colon after administration of neostigmine. *Intensive Care Med* 2004; 30: 730.
286. Herz BL. Colonic anastomotic disruption in myasthenia gravis. Report of two cases. *Dis Colon Rectum* 1987; 30: 809-11.
287. Hirst GR, Karandikar SS, Brown G, Slowey H, Beynon J. Colonic anastomotic disruption in the immediate postoperative period. *Int J Colorectal Dis* 2004; 19: 281-2.
288. Cofer TW Jr, Ray JE, Gathright JB Jr. Does neostigmine cause disruption of large-intestinal anastomoses? A negative answer. *Dis Colon Rectum* 1974; 17: 235-7.
289. Korttila K. The study of postoperative nausea and vomiting. *Br J Anaesth* 1992; 69(Suppl 1): 20S-23S.
290. Ding Y, Fredman B, White PF. Use of mivacurium during laparoscopic surgery: effect of reversal drug on postoperative recovery. *Anesth Analg* 1994; 78: 450-4.
291. Watcha MF, Safavi FZ, McCulloch DA, Tan TS, White PF. Effect of antagonism of mivacurium-induced neuromuscular block on postoperative emesis in children. *Anesth Analg* 1995; 80: 713-7.
292. King MJ, Milazkiewicz R, Carli F, Deacock AR. Influence of neostigmine on postoperative vomiting. *Br J Anaesth* 1988; 61: 403-6.
293. Boeke AJ, de Lange JJ, van Druenen B, Langemeijer JJM. Effect of antagonizing residual neuromuscular block by neostigmine and atropine on postoperative vomiting. *Br J Anaesth* 1994; 72: 654-6.
294. Janhunen L, Tammisto T. Post-operative vomiting after different modes of general anaesthesia. *Ann Chir Gynaecol Fenniae* 1972; 61: 152-9.
295. Hovorka J, Korttila K, Nelskylä K, Soikkeli A, Sarvela J, Paatero H, et al. Reversal of neuromuscular blockade with neostigmine has no effect on the incidence or severity of postoperative nausea and vomiting. *Anesth Analg* 1997; 85: 1359-61.
296. Tramér MR, Fuchs-Buder T. Omitting antagonism of neuromuscular block: effect on postoperative nausea and vomiting and risk of residual paralysis. A systematic review. *Br J Anaesth* 1999; 82: 379-86.
297. Cheng CR, Sessler DI, Apfel CC. Does neostigmine administration produce a clinically important increase in postoperative nausea and vomiting? *Anesth Analg* 2005; 101: 1349-55.
298. Buzello W, Krieg N, Schlickewei A. Hazards of neostigmine in patients with neuromuscular disorders. Report of two cases. *Br J Anaesth* 1982; 54: 529-34.
299. Eldor J, Hoffman B, Davidson JT. Prolonged bradycardia and hypotension after neostigmine administration in a patient receiving

- atenolol. *Anaesthesia* 1987; 42: 1294-7.
300. Seidl DC, Martin DE. Prolonged bradycardia after neostigmine administration in a patient taking nadolol. *Anesth Analg* 1984; 63: 365-7.
301. Eddelston M, Buckley NA, Eyer P, Dawson AH. Management of acute organophosphorus pesticide poisoning. *Lancet* 2008; 371: 597-607.
302. Newmark J. Nerve agents. *Neurologist* 2007; 13: 20-32.
303. Payne JP, Hughes R, Azawi SA. Neuromuscular blockade by neostigmine in anaesthetized man. *Br J Anaesth* 1980; 52: 69-75.
304. Sharma R. Muscle paralysis with an accidental overdosage of neostigmine. *Acta Anaesthesiol Scand* 2008; 52: 1437.
305. Caldwell JE. Reversal of residual neuromuscular block with neostigmine at one to four hours after a single intubating dose of vecuronium. *Anesth Analg* 1995; 80: 1168-74.
306. Yost CS, Maestrone E. Clinical concentrations of edrophonium enhance desensitization of the nicotinic acetylcholine receptor. *Anesth Analg* 1994; 78: 520-6.
307. Legendre P, Ali DW, Drapeau P. Recovery from open channel block by acetylcholine during neuromuscular transmission in zebrafish. *J Neurosci* 2000; 20: 140-8.