

Aktuelle Neubewertungen der Rolle reaktiver Sauerstoffspezies (ROS)

Sebastian Schmeißer, Jena; Michael Ristow, Zürich; Marc Birringer, Fulda

Literatur

28. Quick KL, Ali SS, Arch R et al. (2008) A carboxyfullerene SOD mimetic improves cognition and extends the lifespan of mice. *Neurobiol Aging* 29: 117–128
29. Dai DF, Santana LF, Vermulst M et al. (2009) Overexpression of catalase targeted to mitochondria attenuates murine cardiac aging. *Circulation* 119: 2789–2797
30. Rubner M. III. Das Wachstumsproblem und die Lebensdauer des Menschen und einiger Säugetiere vom energetischen Standpunkt aus betrachtet. In: Rubner M (Hg). *Das Problem der Lebensdauer und seine Beziehungen zum Wachstum und der Ernährung*. R. Oldenbourg, München/Berlin (1908), S. 127–208
31. Pearl R. *The rate of living. Being an account of some experimental studies on the biology of life duration*. Alfred Knopf, New York (1928)
32. McCay CM, Crowel MF, Maynard LA (1935) The effect of retarded growth upon the length of the life span and upon ultimate body size. *J Nutr* 10: 63–79
33. Colman RJ, Anderson RM, Johnson SC et al. (2009) Caloric restriction delays disease onset and mortality in rhesus monkeys. *Science* 325: 201–204
34. Fontana L, Partridge L, Longo VD (2010) Extending healthy life span—from yeast to humans. *Science* 328: 321–326
35. Fontana L, Meyer TE, Klein S, Holloszy JO (2004) Long-term calorie restriction is highly effective in reducing the risk for atherosclerosis in humans. *Proc Natl Acad Sci U S A* 101: 6659–6663
36. Heilbronn LK, de Jonge L, Frisard MI et al. (2006) Effect of 6-month calorie restriction on biomarkers of longevity, metabolic adaptation, and oxidative stress in overweight individuals: a randomized controlled trial. *JAMA* 295: 1539–1548
37. Fontana L, Klein S (2007) Aging, adiposity, and calorie restriction. *JAMA* 297: 986–994
38. Houthoofd K, Braeckman BP, Lenaerts I et al. (2002) Axenic growth up-regulates mass-specific metabolic rate, stress resistance, and extends life span in *Caenorhabditis elegans*. *Exp Gerontol* 37: 1371–1378
39. Hulbert AJ, Clancy DJ, Mair W et al. (2004) Metabolic rate is not reduced by dietary-restriction or by lowered insulin/IGF-1 signalling and is not correlated with individual lifespan in *Drosophila melanogaster*. *Exp Gerontol* 39: 1137–1143
40. Lin SJ, Kaerberlein M, Andalis AA et al. (2002) Calorie restriction extends *Saccharomyces cerevisiae* lifespan by increasing respiration. *Nature* 418: 344–348
41. Nisoli E, Tonello C, Cardile A et al. (2005) Calorie restriction promotes mitochondrial biogenesis by inducing the expression of eNOS. *Science* 310: 314–317
42. Lopez-Lluch G, Hunt N, Jones B et al. (2006) Calorie restriction induces mitochondrial biogenesis and bioenergetic efficiency. *Proc Natl Acad Sci U S A* 103: 1768–1773
43. Schulz TJ, Zarse K, Voigt A et al. (2007) Glucose restriction extends *Caenorhabditis elegans* life span by inducing mitochondrial respiration and increasing oxidative stress. *Cell Metab* 6: 280–293
44. Sharma PK, Agrawal V, Roy N (2010) Mitochondria-mediated hormetic response in life span extension of calorie-restricted *Saccharomyces cerevisiae*. *Age (Dordr)* 33: 143–154.
45. Zuin A, Carmona M, Morales-Ivorra I et al. (2010) Lifespan extension by calorie restriction relies on the Sty1 MAP kinase stress pathway. *Embo J* 29: 981–991
46. Andziak B, O'Connor TP, Qi W et al. (2006) High oxidative damage levels in the longest-living rodent, the naked mole-rat. *Aging Cell* 5: 463–471
47. Labinskyy N, Csiszar A, Orosz Z et al. (2006) Comparison of endothelial function, O₂-* and H₂O₂ production, and vascular oxidative stress resistance between the longest-living rodent, the naked mole rat, and mice. *Am J Physiol Heart Circ Physiol* 291: H2698–H2704
48. Heidler T, Hartwig K, Daniel H, Wenzel U (2010) *Caenorhabditis elegans* lifespan extension caused by treatment with an orally active ROS-generator is dependent on DAF-16 and SIR-2.1. *Biogerontology* 11: 183–195
49. Lee SJ, Hwang AB, Kenyon C (2010) Inhibition of respiration extends *C. elegans* lifespan via reactive oxygen species that increase HIF-1 activity. *Curr Biol* 20: 2131–2136
50. Yang W, Hekimi S (2010) A mitochondrial superoxide signal triggers increased longevity in *Caenorhabditis elegans*. *PLoS Biol* 8: e1000556
51. Ristow M, Schmeisser S (2011) Extending life span by increasing oxidative stress. *Free Radic Biol Med* 51: 327–336
52. Birringer M, Ristow M (2012) Effektivität und Risiken der Supplementierung mit Antioxidanzien – Teil 1. *Ernährungs Umschau* 59: 10–14
53. Ristow M, Zarse K, Oberbach A et al. (2009) Antioxidants prevent health-promoting effects of physical exercise in humans. *Proc Natl Acad Sci* 106: 8665–8670
54. Bjelakovic G, Nikolova D, Gluud LL et al. (2007) Mortality in randomized trials of antioxidant supplements for primary and secondary prevention: systematic review and meta-analysis. *JAMA* 297: 842–857
55. Sena LA, Chandel NS (2012) Physiological roles of mitochondrial reactive oxygen species. *Molecular Cell* 48: 158–167
56. Choi WS, Eom DS, Han BS et al. (2004) Phosphorylation of p38 MAPK induced by oxidative stress is linked to activation of both caspase-8- and -9-mediated apoptotic pathways in dopaminergic neurons. *J Biol Chem* 279: 20451–20460

57. Pouyssegur J, Mechta-Grigoriou F (2006) Redox regulation of the hypoxia-inducible factor. *Biol Chem* 387: 1337–1346
58. Xu S, Touyz RM (2006) Reactive oxygen species and vascular remodelling in hypertension: still alive. *Can J Cardiol* 22: 947–951
59. Higaki Y, Mikami T, Fujii N et al. (2008) Oxidative stress stimulates skeletal muscle glucose uptake through a phosphatidylinositol 3-kinase-dependent pathway. *Am J Physiol Endocrinol Metab* 294: E889–E897
60. Zuin A, Castellano-Estève D, Ayte J, Hidalgo E (2010) Living on the edge: stress and activation of stress responses promote lifespan extension. *Aging (Albany NY)* 2: 231–237
61. Cross JV, Templeton DJ (2006) Regulation of signal transduction through protein cysteine oxidation. *Antioxid Redox Signal* 8: 1819–1827
62. Jasper H (2008) SKNy worms and long life. *Cell* 132: 915–916
63. Ishii T, Itoh K, Yamamoto M (2002) Roles of Nrf2 in activation of antioxidant enzyme genes via antioxidant responsive elements. *Methods Enzymol* 348: 182–190
64. Kensler TW, Wakabayashi N, Biswal S (2007) Cell survival responses to environmental stresses via the Keap1-Nrf2-ARE pathway. *Annu Rev Pharmacol Toxicol* 47: 89–116
65. Copple IM, Goldring CE, Kitteringham NR, Park BK (2008) The Nrf2-Keap1 defence pathway: role in protection against drug-induced toxicity. *Toxicology* 246: 24–33
66. Dreger H, Westphal K, Weller A, et al. (2009) Nrf2-dependent upregulation of antioxidative enzymes: a novel pathway for proteasome inhibitor-mediated cardioprotection. *Cardiovasc Res* 83: 354–361
67. Sykiotis GP, Habeos IG, Samuelson AV, Bohmann D (2011) The role of the antioxidant and longevity-promoting Nrf2 pathway in metabolic regulation. *Curr Opin Clin Nutr Metab Care* 14: 41–48
68. Vanfleteren JR (1993) Oxidative stress and ageing in *Caenorhabditis elegans*. *Biochem J* 292(Pt 2): 605–608
69. Yu BP, Chung HY (2001) Stress resistance by caloric restriction for longevity. *Ann NY Acad Sci* 928: 39–47
70. Lithgow GJ, Walker GA (2002) Stress resistance as a determinate of *C. elegans* lifespan. *Mech Ageing Dev* 123: 765–771
71. Murakami S, Salmon A, Miller RA (2003) Multiplex stress resistance in cells from long-lived dwarf mice. *Faseb J* 17: 1565–1566
72. Benedetti MG, Foster AL, Vantipalli MC et al. (2008) Compounds that confer thermal stress resistance and extended lifespan. *Exp Gerontol* 43: 882–891
73. Ungvari Z, Parrado-Fernandez C, Csiszar A, de Cabo R (2008) Mechanisms underlying caloric restriction and lifespan regulation: implications for vascular aging. *Circ Res* 102: 519–528
74. Schulz HPF (1887) Zur Lehre von der Arzneiwirkung. *Virchows Archiv für pathologische Anatomie und Physiologie und für klinische Medizin* 108: 423–445
75. Southam CM, Ehrlich J (1943) Effects of extract of western red-cedar heartwood on certain wood-decaying fungi in culture. *Phytopathology* 33: 517–52
76. Calabrese EJ, Baldwin LA (2002) Defining hormesis. *Hum Exp Toxicol* 21: 91–97
77. Calabrese EJ, Bachmann KA, Bailer AJ et al. (2007) Biological stress response terminology: Integrating the concepts of adaptive response and preconditioning stress within a hormetic dose-response framework. *Toxicol Appl Pharmacol* 222: 122–128
78. Tapia PC (2006) Sublethal mitochondrial stress with an attendant stoichiometric augmentation of reactive oxygen species may precipitate many of the beneficial alterations in cellular physiology produced by caloric restriction, intermittent fasting, exercise and dietary phytonutrients: 'Mitohormesis' for health and vitality. *Med Hypotheses* 66: 832–843
79. McCord JM (2000) The evolution of free radicals and oxidative stress. *Am J Med* 108: 652–659
80. Dröge W (2002) Free radicals in the physiological control of cell function. *Physiol Rev* 82: 47–95
81. Beuster G, Zarse K, Kaleta C et al. (2011) Inhibition of alanine aminotransferase in silico and in vivo promotes mitochondrial metabolism to impair malignant growth. *J Biol Chem* 286: 22323–22330
82. Powers SK, Jackson MJ (2008) Exercise-induced oxidative stress: cellular mechanisms and impact on muscle force production. *Physiol Rev* 88: 1243–1276
83. Bishop NA, Guarente L (2007) Two neurons mediate diet-restriction-induced longevity in *C. elegans*. *Nature* 447: 545–549
84. Koizumi A, Weindruch R, Walford RL (1987) Influences of dietary restriction and age on liver enzyme activities and lipid peroxidation in mice. *J Nutr* 117: 361–367
85. Semsei I, Rao G, Richardson A (1989) Changes in the expression of superoxide dismutase and catalase as a function of age and dietary restriction. *Biochem Biophys Res Commun* 164: 620–625
86. Rao G, Xia E, Nadakavukaren MJ, Richardson A (1990) Effect of dietary restriction on the age-dependent changes in the expression of antioxidant enzymes in rat liver. *J Nutr* 120: 602–609
87. Pieri C, Falasca M, Marcheselli F et al. (1992) Food restriction in female Wistar rats: V. Lipid peroxidation and antioxidant enzymes in the liver. *Arch Gerontol Geriatr* 14: 93–99
88. Youngman LD, Park JY, Ames BN (1992) Protein oxidation associated with aging is reduced by dietary restriction of protein or calories. *Proc Natl Acad Sci U S A* 89: 9112–9116
89. Xia E, Rao G, van Remmen H et al. (1995) Activities of antioxidant enzymes in various tissues of male Fischer 344 rats are altered by food restriction. *J Nutr* 125: 195–201
90. Masoro EJ (1998) Hormesis and the antiaging action of dietary restriction. *Exp Gerontol* 33: 61–66
91. Barros MH, Bandy B, Tahara EB, Kowaltowski AJ (2004) Higher respiratory activity decreases mitochondrial reactive oxygen release and increases life span in *Saccharomyces cerevisiae*. *J Biol Chem* 279: 49883–49888
92. Mesquita A, Weinberger M, Silva A et al. (2010) Caloric restriction or catalase inactivation extends yeast chronological lifespan by inducing H₂O₂ and superoxide dismutase activity. *Proc Natl Acad Sci U S A* 107: 15123–15128
93. Rattan SI, Demirovic D. Hormesis as a Mechanism for the Anti-Aging Effects of Calorie Restriction. In: Everitt AV, Rattan SIS, Couteur DG, Cabo RD (Hg). *Calorie Restriction, Aging and Longevity*. Springer Netherlands (2010), S. 233–245
94. Mair W, Piper MD, Partridge L (2005) Calories do not explain extension of life span by dietary restriction in *Drosophila*. *PLoS Biol* 3: e223
95. Lee SJ, Murphy CT, Kenyon C (2009) Glucose shortens the life span of *C. elegans* by down-regulating DAF-16/FOXO activity and aquaporin gene expression. *Cell Metab* 10: 379–391
96. Schlotterer A, Kukudov G, Bozorgmehr F et al. (2009) *C. elegans* as model for the study of high glucose mediated lifespan reduction. *Diabetes* 58: 2450–2456
97. Forsythe CE, Phinney SD, Fernandez ML et al. (2008) Comparison of low fat and low carbohydrate diets on circulating fatty acid composition and markers of inflammation. *Lipids* 43: 65–77
98. D'Antona G, Ragni M, Cardile A et al. (2010) Branched-chain amino acid supplementation

- promotes survival and supports cardiac and skeletal muscle mitochondrial biogenesis in middle-aged mice. *Cell Metab* 12: 362–372
99. Birringer M (2011) Hormetics: Dietary Triggers of an Adaptive Stress Response. *Pharm Res* 28: 2680–2694
100. JG, Rogina B, Lavu S et al. (2004) Sirtuin activators mimic caloric restriction and delay ageing in metazoans. *Nature* 430: 686–689
101. Shen LR, Xiao F, Yuan P et al. (2012) Curcumin-supplemented diets increase superoxide dismutase activity and mean lifespan in *Drosophila*. *Age* [DOI 10.1007/s11357-012-9438-2]
102. Higuchi M, Cartier LJ, Chen M, Holloszy JO (1985) Superoxide dismutase and catalase in skeletal muscle: adaptive response to exercise. *J Gerontol* 40: 281–286
103. Lindsted KD, Tonstad S, Kuzma JW (1991) Self-report of physical activity and patterns of mortality in Seventh-Day Adventist men. *J Clin Epidemiol* 44: 355–364
104. Manini TM, Everhart JE, Patel KV et al. (2006) Daily activity energy expenditure and mortality among older adults. *JAMA* 296: 171–179
105. Warburton DE, Nicol CW, Bredin SS (2006) Health benefits of physical activity: the evidence. *Can Med Ass J* 174: 801–809
106. Lanza IR, Short DK, Short KR et al. (2008) Endurance exercise as a countermeasure for aging. *Diabetes* 57: 2933–2942
107. Sanchis-Gomar F, Olaso-Gonzalez G, Corella D et al. (2011) Increased average longevity among the “Tour de France” cyclists. *Int J Sports Med* 32: 644–647
108. Davies KJ, Quintanilha AT, Brooks GA, Packer L (1982) Free radicals and tissue damage produced by exercise. *Biochem Biophys Res Commun* 107: 1198–1205
109. Powers SK, Ji LL, Leeuwenburgh C (1999) Exercise training-induced alterations in skeletal muscle antioxidant capacity: a brief review. *Med Sci Sports Exerc* 31: 987–997
110. Chevion S, Moran DS, Heled Y et al. (2003) Plasma antioxidant status and cell injury after severe physical exercise. *Proc Natl Acad Sci U S A* 100: 5119–5123
111. Gomez-Cabrera MC, Domenech E, Romagnoli M et al. (2008) Oral administration of vitamin C decreases muscle mitochondrial biogenesis and hampers training-induced adaptations in endurance performance. *Am J Clin Nutr* 87: 142–149
112. Radak Z, Chung HY, Koltai E et al. (2008) Exercise, oxidative stress and hormesis. *Ageing Research Reviews* 7: 34–42