9
BÖLÜM

ELEKTROFİZYOLOJİ

Sami YILMAZ[1]

1. Giriş

Göz yüzeyi, periorbital cilt, ya da kafa derisi üzerine yerleştirilen elektrotlar kullanılarak, görsel uyaranların elektrik potansiyellerine çevrilerek kaydedilmesi işlemi, gözün ve görme yollarının elektrofizyolojik değerlendirilmesi olarak isimlendirilir. Görme sistemi içerisinde farklı konumlarda yer alan hücre türleri ile ilgili girişimsel olmayan, objektif bilgiler sağlar. Uluslararası Klinik Görsel Elektrofizyoloji Derneği (ISCEV) gözün ve görme yollarının elektrofizyolojik değerlendirilmesi için standartlar ve rehberler yayınlamaktadır (1-5).

Santral siniri sisteminin geri kalanı gibi, retina da embriyolojik olarak nöral tüpten köken alır (6). Retina çevresel enerjiyi elektrik potansiyellerine çeviren özelleşmiş bir hücre yapısına sahiptir. Retina iki kısımdan oluşmaktadır: 1) Işığı elektrik potansiyellerine çeviren fotoreseptör hücreler olarak adlandırılan rod (basil) ve kon (koni) hücrelerinden oluşan sensöriyel (duyusal) retina ve 2) bipolar, horizontal, amakrin ve gangliyon hücrelerinden oluşan nöral retina (7).

Retina bu özelleşmiş hücrelerin çekirdeklerinden ve onların uzantılarından oluşmuş düzenli bir tabakalı yapıya sahiptir. Retina pigment epitel tabakasının hemen üzerinde yerleşen dış nükleer tabaka (DNL), rod ve kon hücrelerinin hücre gövdelerini içermekte, iç nükleer tabaka (İNL) horizontal, bipolar, amakrin ve glial hücrelerin (Müller hücreleri) hücre gövdelerinden oluşmaktatır. Gangliyon ve amakrin hücre gövdelerinden oluşan gangliyon hücre tabakası (GHT) vitreusa yakın yüzeyde yer almaktadır. Gangliyon hücrelerin aksonları optik siniri oluşturur. Bu hücre gövdelerinden oluşan 3 tabaka arasında hücrelerin dentrit

[1] Op. Dr. Sami YILMAZ, Bursa Retina Göz Hastanesi samifmf1978@yahoo.com

Kaynaklar

1. McCulloch DL, Marmor MF, Brigell MG, et al. ISCEV standart for full-field clinical electroretinography (2015 update). Doc Ophthalmol 2015;130:1-12.
2. Bach M, Brigell MG, Hawlina M, et al. ISCEV standart for clinical pattern electroretinography (PERG): 2012 update. Doc Ophthalmol 2013;126:1-7.
3. Hood DC, Bach M, Brigell M, et al. ISCEV standart for clinical multifocal electroretinography (mfERG) (2011 edition). Doc Ophthalmol 2012;124:1-13.
4. Constable PA, Bach M, Frishman LJ, et al. International society for clinical electrophysiology of vision. ISCEV standart for clinical electro-oculography (2017 update). Doc Ophthalmol 2017;134:1-9.
5. Odom JV, Bach M, Brigell M, et al. ISCEV standart for clinical visual evoked potentials (2016 update). Doc Ophthalmol 2016;133(1):1-9.
6. O'Rahilly R, Müller F. Neurulation in the normal human embryo. Ciba Found Symp 1994;181:70-82, discussion 82-9.
7. Masland RH. The functional architecture of the retina. Sci Am 1986;255(6):102-11.
8. Wassle H. Parallel processing in the mammalian retina. Nat Rev Neurosci 2004;5(10):747-57.
9. Curcio CA, Sloan KR, Kalina RE, Hendrickson AE. Human photoreceptor topography. J Comp Neurol 1990;292(4):497-523.
10. Ahnelt PK, Kolb H. The mammalian photoreceptor mosaic-adaptive design. Prog Retin Eye Res. 2000;19(6):711-77.
11. DeMonasterio FM, Schein SJ, McCrane EP. Staining of blue-sensitive cones of the macaque retina by a fluorescent dye. Science 1981;213(4513):1278-81.
12. Chun MH, Grunert U, Martin PR, Wässle H. The synaptic complex of cones in the fovea and in the periphery of the macaque monkey retina. Vision Res 1996;36(21):3383-95.
13. Lennie P, Fairchild MD. Ganglion cell pathways for rod vision. Vision Res 1994;34(4):477-82.
14. Mills SL, Massey SC. AII amacrine cells limit scotopic acuity in central macaque retina: A confocal analysis of calretinin labeling. J Comp Neurol 1999;411(1):19-34.
15. Rao-Mirotznik R, Harkins AB, Buchsbaum G, Sterling P. Mammalian rod terminal: Architecture of a binary synapse. Neuron 1995;14(3):561-9.
16. Verweij J, Kamermans M, Spekreijse H. Horizontal cells feed back to cones by shifting the cone calcium-current activation range. Vision Res 1996;36(24):3943-53.
17. Sterling P. How retinal circuits optimize the transfer of visual information. In: Chalupa LM, editor. The visual neurosciences. Boston, MA: Cambridge; 2004. p. 234-59.
18. Kamermans M, Kraaij DA, Spekreijse H. The cone/horizontal cell network: a possible site for color constancy. Vis Neurosci 1998;15(5):787-97.
19. Dacey DM, Lee BB, Stafford DK, et al. Horizontal cells of the primate retina: cone specificity without spectral opponency. Science 1996;271(5249):565-9.
20. Packer OS, Dacey DM. Receptive field structure of H1 horizontal cells in macaque

monkey retina. J Vis 2002;2(4):272-92.

21. Boycott BB, Wassle H. Morphological classification of bipolar cells of the primate retina. Eur J Neurosci 1991;3(11):1069-88.
22. Schubert T, Kerschensteiner D, Eggers ED, et al. Development of the presynaptic inhibition onto retinal bipolar cell axon terminals is subclass-specific. J Neurophysiol 2008;100(1):304-16.
23. Dhingra A, Lyubarsky A, Jiang M, et al. The light response of ON bipolar neurons requires G[alpha]o. J Neurosci 2000;20(24):9053-8.
24. MacNeil AA, Masland RH. Extreme diversity among amacrine cells: implications for function. Neuron 1998;20(5):971-82.
25. Vardi N, Smith RG. The AII amacrine network: coupling can increase correlated activity. Vision Res 1996;36(23):3743-57.
26. Sanes JR, Masland RH. The types of retinal ganglion cells: current status and implications for neuronal classification. Annu Rev Neurosci 2015;38:221-46.
27. Gjötterberg M. Electrodes for electroretinography: a comparison of four different types. Arch Ophthalmol 1986;104:569-70.
28. Brown KT. The electroretinogram: its components and their origins. Vision Res 1968;8:633-77.
29. Newman EA, Odette LL. Model of electroretinogram b-wave generation: a test of the K+ hypothesis. J Neurophysiol 1984;51:164-82.
30. Wachtmeister L, Dowling JE. The oscillatory potentials of the mudpuppy retina. Invest Ophthalmol Vis Sci 1978;17:1176-88.
31. Kondo M, Piao CH, Tanikawa A, et al. Amplitude decrease of photopic ERG b-wave at higher stimulus intensities in humans. Jpn J Ophthalmol 2000;44:20-8.
32. Peachey NS, Alexander KR, Fishman GA, Derlacki DJ. Properties of the human cone system electroretinogram during light adaptation. Appl Opt 1989;28:1145-50.
33. Berninger T, Schuurmans RP. Spatial tuning of the pattern ERG across temporal frequency. Doc Ophthalmol 1985;61:17-25.
34. Marmor MF, Holder GE, Porciatti V, et al. Guidelines for basic pattern electroretinography: recommendations by the International Society for Clinical Electrophysiology of Vision. Doc Ophthalmol 1995-1996;91:291-8.
35. Holder GE. PERG abnormalities in anterior visual pathway disease. Electroencephalogr Clin Neurophysiol 1985;61:365.
36. Sutter EE, Tran D. The field topography of ERG components in man-I. The photopic luminance response. Vision Res 1992;32:433-46.
37. Sutter E. The interpretation of multifocal binary kernels. Doc Ophthalmol 2000;100:49-75.
38. Hood DC, Freishman LJ, Saszik S, et al. Retinal origins of the primate multifocal ERG: implications for the human response. Invest Ophthalmol Vis Sci 2002;43:1673-85.
39. Du Bois Reymond EH. Chapter 3. Von dem ruhen Nervenstrome. Untersuchungen

Über Thierische Electricität, vol. 2. Berlin: G Reimer; 1849. 251-88.

40. Arden GB, Barrada A, Kelsey JH. New clinical test of retinal function based upon the standing potential of the eye. Br J Ophthalmol 1962;46:449-67.
41. Robson AG, Nilsson J, Li S, et al. ISCEV guide to visual electrodiagnostic procedures. Doc Ophthalmol 2018; 136:1-26.
42. Weleber RG, Watzke RC, Shults WT, et al. Clinical and electrophysiologic characterization of paraneoplastic and autoimmune retinopatihies associated with antienolase antibodies. Am J Ophthalmol 2005;139:780-94.
43. Galloway NR, Barber C. The pattern evoked response in disorders of the optic nerve. Doc Ophthalmol 1986;63:31-6.
44. Holder GE. The incidence of abnormal pattern electroretinography in optic nerve demyelination. Electroenceph Clin Neurophysiol 1991;78:18-26.
45. Thompson PD, Mastaglia FL, Carroll WM. Anterior ischaemic optic neuropathy: a correlative clinical and visual evoked potential study of 18 patients. J Neurol Neurosurg Psychiatry 1986;49:128-35.
46. Livingstone IR, Mastaglia FL, Howe JW, Aherne GE. Leber's optic neuropathy:clinical and visual evoked response studies in asymptomatic and symptomatic members of a 4 generation family. Br J Ophthalmol 1980;64(10):751-7.
47. Flanagan JG, Harding GF. Multichannel visual evoked potentials in early compressive lesions of the chiasma. Doc Ophthalmol 1988;69:271-81.
48. Holder GE, Votruba M, Carter AC, et al. Electrophysiological findings in dominant optic atrophy linking to the OPA1 locus on chromosome 3q 28-qter. Doc Ophthalmol 1998-1999;95:217-28.
49. Troncoso J, Mancall EL, Schatz NY. Visual evoked response in pernicious anemia. Arch Neurol 1979;36:168-9.
50. Bodis WI, Atkin A, Raab E, Wolkstein M. Visual associated cortex and vision in man: pattern evoked occipital potentials in a blind boy. Science 1977;198:629-31.
51. Robson JG, Frishman LJ. Response linearity and kinetics of the cat retina: the bipolar cell component of the dark-adapted electroretinogram. Vis Neurosci 1995;12:837-50.
52. Berson EL. Retinitis pigmentosa and allied disease: applications of electroretinographic testing. Int Ophthalmol 1981;4:7-22.
53. Schubert G, Bornschein H. Analysis of the human retinogram. Ophthalmologica 1952;123(6):396-413.
54. Riggs LA. Electroretinography in cases of night blindness. Am J Ophthalmol 1954;38(1:2):70-8.
55. Carr RE, Ripps H, Siegel IM. Visual pigment kinetics and adaptation in fundus albipunctatus. In: Dodt E, Pearlman JT (eds) XIth I.S.C.E.R.G. Symposium. Documenta Ophthalmolmologica Proceedings Series, Springer, Dordrecht, vol 4. 1974:193-204.
56. Niwa Y, Kondo M, Ueno S, et al. Cone and rod dysfuncyion in fundus albipunctatus with RDH5 mutation: an electrophysiological study. Invest Ophthalmol Vis Sci 2005;46(4):1480-5.

57. Carr RE, Gouras P. Oguchi's disease. Arch Ophthalmol 1965;73:646-56.
58. McBain VA, Egan CA, Pieris SJ, et al. Functional observations in vitamin A deficiency: diagnosis and time course of recovery. Eye (Lond) 2007;21(3):367-76.
59. Miyake Y, Yagasaki K, Horiguchi M, et al. Congenital stationary night blindness with negative electroretinogram: a new classification. Arch Ophthalmol 1986;104(7):1013-20.
60. Miyake Y. [Establishment of the concept of new clinical entities complete and incomplete form of congenital stationary night blindness]. Nihon Ganka Gakkai Zasshi 2002;106(12):737-55, discussion 56.
61. Alexander KR, Fishman GA, Peachey NS, et al. "On" response defect in paraneoplastic night blindness with cutaneous malignant melenoma. Invest Ophthalmol Vis Sci 1992;33(3):477-83.
62. Simunovic MP, Moore AT. The cone dystrophies. Eye (Lond) 1998;12(Pt 3b):553-65.
63. Robson AG, Michaelides M, Luong VA, et al. Functional correlates of fundus autofluorescence abnormalities in patients with RPGR or RIMS 1 mutations causing cone or cone rod dystophy. Br J Ophthalmol 2008;92(1):95-102.
64. O'Connor PS, Tredici TJ, Ivan DJ, et al. Achromatopsia: clinical diagnosis and treatment. J Clin Neuroophthalmol 1982;2(4):219-26.
65. Gouras P, MacKay CJ. Electroretinographic responses of the short-wavelength-sensitive cones. Invest Ophthalmol Vis Sci 1990;31(7):1203-9.
66. Hirose T, Katsumi O, Pruett RC, et al. Retinal function in birdshot retinochoroidopathy. Acta Ophthalmol (Copenh) 1991;69(3):327-37.
67. Gass JD, Agarwal A, Scott IU. Acute zonal occult outer retinopathy: a long-term follow-up study. Am J Ophthalmol 2002;134(3):329-39.
68. Henkes HE. Electroretinography in circulatory disturbances of the retina. II: The electroretinogram in cases of occlusion of the central retinal artery or of its branches. Arch Ophthalmol 1954;51(1):42-53.
69. Ventura LM, Porciatti V. Pattern electroretinogram in glaucoma. Curr Opinion in Ophthalmol 2006;17:196-202.
70. Good PA, Searle AE, Campbell S, Crews SJ. Value of the ERG in congenital nystagmus. Br J Ophthalmol 1989;73(7):512-5.
71. Hayreh SS, Klugman MR, Podhajsky P, Kolder HE. Electroretinography in central retinal vein occlusion. Correlation of electroretinographic changes with pupillary abnormalities. Graefes Arch Clin Exp Ophthalmol 1989;227(6):549-61.
72. Brown GC, Magargal LE. The ocular ischemic syndrome. Int Ophthalmol 1988;11(4):239-51.
73. Tzekov R, Arden GB. The electroretinogram in diabetic retinopathy. Surv Ophthalmol 1999;44(1):53-60.
74. Galloway NR. Electrophysiological testing of eyes with opaque media. Eye 1988;2:615-24.
75. Fishman GA, Weinberg AB, McMahon TT. X-linked recessive retinitis pigmentosa. Clinical characteristics of carriers. Arch Ophthalmol 1986;104(9):1329-35.

76. Holder GE, Robson AG, Pavesio C, et al. Electrophysiological characterisation and monitoring in the management of birdshot chorioretinopathy. Br J Ophthalmol 2005;89(6):709-18.
77. Maturi RK, Yu M, Weleber RG. Multifocal electroretinographic evaluation of long-term hydroxychloroquine users. Arch Ophthalmol 2004;122(7):973-81.
78. Imaizumi M, Matsumoto CS, Yamada K, et al. Electroretinographic assessment of early changes in ocular siderosis. Opthalmologica 2000;214(5):354-9.
79. Brodie SE. Tips and tricks for successful electroretinography in children. Curr Opin Ophthalmol 2014;25(5):366-73.
80. Sokol S. Abnormal evoked potential latencies in amblyopia. Br J Ophthalmol 1983;67:310-4.
81. Lambert SR, Kriss A, Taylor D. Delayed visual maturation: a longitudinal clinical and electrophysiological assessment. Ophthalmology 1989;96(4):524-9.
82. Ponjavic V, Andréasson S. Multifocal ERG and full-field ERG in patients on long-term vigabatrin medication. Doc Ophthalmol 2001;102(1):63-72.
83. Cooper LZ, Krugman S. Clinical manifestations of postnatal and congenital rubella. Arch Ophthalmol 1967;77(4):434-9.
84. Berger W, Kloeckener-Gruissem B, Neidhart J. The molecular basis of human retinal and vitreoretinal disease. Prog Retin Eye Res 2010;29:335-75.
85. HGMD. Human Gene Mutation Database, <http://www.hgmd.cf.ac.uk/>.
86. Nussbaum RL, McInnes RR, Williard HF. Thompson and Thompson Genetics in medicine. 8th ed. Philadelphia, PA: Saunders Elsevier; 2015.
87. Weleber RG, Carr RE, Murphey WH, et al. Phenotypic variation including retinitis pigmentosa, pattern dystophy, and fundus flavimaculatus in a single family with a deletion of codon 153 or 154 of the peripherin/RDS gene. Arch Ophthalmol 1993;111:1531-42.
88. Lyon MF. The Lyon and the LINE hypothesis. Semin Cell Dev Biol 2003;14:313-18.
89. Pettersson E, Lundeberg J, Ahmadian A. Generations of sequencing technologies. Genomics 2009;93:105-11.
90. Arnold JJ, Sarks JP, Killingsworth MC, et al. Adult vitelliform macular degeneration: a clinicopathological study. Eye (Lond) 2003;17(6):717-26.
91. Shah KH, Levinson RD, Yu F, et al. Birdshot chorioretinopathy. Surv Ophthalmol 2005;50(6):519-41.
92. Priem HA, Kijlstra A, Noens L, et al. HLA typing in birdshot chorioretinopathy. Am J Ophthalmol 1988;105(2):182-5.
93. Brucker AJ, Deglin EA, Bene C, et al. Subretinal choroidal neovascularization in birdshot retinochoroidopathy. Am J Ophthalmol 1985;99(1):40-4.
94. Miller SA, Bresnick GH, Chandra SR. Choroidal neovascular membrane in Best's vitelliform macular dystrophy. Am J Ophthalmol 1976;82(2):252-5.
95. Miller SA. Multifocal Best's vitelliform dystrophy. Arch Ophthalmol 1977;95(6):984-90.

96. Testa F, Rossi S, Passerini I, et al. A normal electro-oculography in a family affected by best disease with a novel spontaneous mutation of the BEST1 gene. Br J Ophthalmol 2008;92(11):1467-70.
97. Goebel HH. The neuronal ceroid-lipofuscinoses. Semin Pediatr Neurol 1996;3(4):270-8.
98. Kufs H. Über einen Fall von spätester Form der amaurotischen Idiotie mit dem Beginn im 42 und Tod im 59 Lebens-jahre in klinischer, histologischer und Vererbungs-pathologischer Beziehung. Z ges Neurol 1931;137:432-48.
99. Weleber RG. The dystrophic retina in multisystem disorders: the electroretinogram in neuronal ceroid lipofuscinoses. Eye (Lond) 1998;12(Pt 3b):580-90.
100. Rowe SE, Trobe JD, Sieving PA. Idiopathic photoreceptor dysfunction causes unexplained visual acuity loss in later adulthood. Ophthalmology 1990;97(12):1632-7.
101. Robson AG, Michaelides M, Luong VA, et al. Functional correlates of fundus autofluorescence abnormalities in patients with RPGR or RIMS1 mutations causing cone or cone rod dystrophy. Br J Ophthalmol 2008;92(1):95-102.
102. Celesia GG, Kaufman D. Pattern ERGs and visual evoked potentials in maculopathies and optic nerve diseases. Invest Ophthalmol Vis Sci 1985;26:726-35.
103. Zeitz C, Robson AG, Audo I. Congenital stationary night blindness: an analysis and update of genotype-phenotype correlations and pathogenic mechanism. Prog Retin Eye Res 2015;45:58-110.
104. Bijveld MM, Florijn RJ, Bergen AA, et al. Genotype and phenotype of 101 Dutch patients with congenital stationary night blindness. Ophthalmology 2013;120(10):2072-81.
105. Rosenberg T, Haim M, Piczenik Y, et al. Autosomal dominant stationary night-blindness: a large family rediscovered. Acta Ophthalmol (Copenh) 1991;69(6):694-702.
106. Niwa Y, Kondo M, Ueno S, et al. Cone and rod dysfunction in fundus albipunctatus with RDH5 mutation: an electrophysiological study. Invest Ophthalmol Vis Sci 2005;46(4):1480-5.
107. Gouras P. Electroretinography: some basic principles. Invest Ophthalmol 1970;9(8):557-69.
108. Franceschetti A, Francois J, Babel J. Chorioretinal heredodegenerations. Springfield, IL: Charles C Thomas;1974.
109. Lambert SR, Kriss A, Taylor D, et al. Follow-up and diagnostic reappraisal of 75 patients with Leber's congenital amaurosis. Am J Ophthalmol 1989;107:624-31.
110. Majander A, Robson AG, Joãc C, et al. The pattern of retinal ganglion cell dysfunction in Leber hereditary optic neuropathy. Mitochondrion 2017;36:138-49.
111. Blair NP, Goldberg MF, Fishman GA, Salzano T. Autosomal dominant vitreoretinochoroidopathy (ADVIRC). Br J Ophthalmol 1984;68(1):2-9.
112. Han DP, Lewandowski MF. Electro-oculography in autosomal dominant vitreoretinochoroidopathy. Arch Ophthalmol 1992;110(11):1563-7.
113. Kinnick TR, Mullins RF, Dev S, et al. Autosomal recessive vitelliform macular dystrophy in a large cohort of vitelliform macular dystrophy patients. Retina

2011;31(3):581-95.

114. Hsieh RC, Fine BS, Lyons JS. Patterned dystrophies of the retinal pigment epithelium. Arch Ophthalmol 1977;95(3):429-35.
115. Brinton GS, Norton EW, Zahn JR, Knighton RW. Ocular quinine toxicity. Am J Ophthalmol 1980;90(3):403-10.
116. Miller FS 3rd, Bunt-Milam AH, Kaline RE. Clinical-ultrastructural study of thioridazine retinopathy.Ophthalmology 1982;89(12):1478-88.
117. Kertes PJ, Lee TK, Coupland SG. The utility of multifocal electroretinography in monitoring drug toxicity: deferoxamine retinopathy. Can J Ophthalmol 2004;39:656-61.
118. Tanino TO. Studies on pigmentary retinal dystrophy. II. Recordability of electroretinogram and the mode of inheritance. Jpn J Ophthalmol 1976;20:482-6.
119. Berson EL, Sandberg MA, Rosner B, et al. Natural course of retinitis pigmentosa over a three-year interval. Am J Ophthalmol 1985;99(3):240-51.
120. Heckenlively JR, Yoser SL, Friedman LH, Oversier JJ. Clinical findings and common symptoms in retinitis pigmentosa. Am J Ophthalmol 1988;105:504-11.
121. Berson EL, Howard J. Temporal aspects of the electroretinogram in sector retinitis pigmentosa. Arch Ophthalmol 1971;86:653-65.
122. Cotterman CW, Falls HF, Neel JV. Some hereditary diseases having subclinical manifestations in carriers. Genetics 1948;33(6):608.
123. Franceschetti A, Francois J, Babel J. Retinitis punctata albescens. In Franceschetti A, Francois J, Babel J, editors. Chorioretinal heredodegenerations. Springfield, IL: Charles C Thomas;1974. p. 222-31.
124. Scholl HP, Besch D, Vonthein R, et al. Alterations of slow and fast rod ERG signals in patients with molecularly confirmed Stardardt disease type 1. Invest Ophthalmol Vis Sci 2002;43(4):1248-56.
125. Sikkink SK, Biswas S, Parry NR, et al. X-linked retinoschisis: an update. J Med Genet 2007;44(4):225-32.