ORIGINAL

Analyses of the characteristics of potential and cross-talk at each electrode in electro-oculogram

Kayo Shinomiya[1)], Nobuyuki Itsuki[2)], Masanori Kubo[3)], and Hiroshi Shiota[1)]

[1)]*Department of Ophthalmology and Visual Neuroscience, Institute of Health Biosciences, The University of Tokushima Graduate School, Tokushima, Japan ;* [2)]*Niihama National College of Technology, Ehime, Japan ; and* [3)]*Kubo Eye Clinic, Kagawa, Japan*

Abstract : We placed negative electrodes on the body and positive electrodes at the medial and lateral canthi, measured their potentials separately, evaluated their characteristics, and analyzed cross-talk.
We recorded EOG in 6 normal subjects and found the following. The potential at the medial was lower than that at the lateral canthus in the bilateral eyes. The polarity of waves at the lateral was reverse to that at the medial canthus in the bilateral eyes. We recorded EOG in 6 patients with unilateral anophthalmia and found the following. On the anophthalmia side, the potential at the lateral was considerably lower than that at the medial canthus. The polarity of the potential was the same between the medial and lateral canthi.
The mean cross-talk to the medial canthus on the anophthalmia side was 8.7%-54.0% of the potential at the medial canthus on the normal side. The mean cross-talk to the lateral canthus on the anophthalmia side was 4.4%-16.9%. The influence of cross-talk of the other eye was marked at the medial but slight at the lateral canthus. In EOG recording, results with minimum errors due to cross-talk can be obtained by paying attention to the potential at the lateral canthus. J. Med. Invest. 55 : 120-126, February, 2008

Keywords **:** *Electro-oculogram, cross-talk, contralateral effect, unilateral anophthalmia*

INTRODUCTION

In the eyeball, a very weak electric current runs from the corneal toward the retinal side, and there is always a potential difference called the retinal resting potential (RP). RP in the normal human eye was first observed by Dewar in 1877 and subsequently studied by Schott, Miles (1, 2) and Arden (3, 4), and a record of RP was termed an electrooculogram (EOG) by Carmichael and Darborn (5).

At present, EOG is used for the evaluation of oculomotor abnormalities such as nystagmus, strabismus, and supranuclear oculomotor dysfunction (6, 7). In addition, EOG is recorded for a long time with changes in the adaptation state, and used for the examination of the function of the retinal deep area such as the retinal pigment epithelium based on changes in its amplitude (8, 9).

However, since EOG is affected by measurement conditions and environments, its reproducibility is not always high. One of the associated errors concerns the influence of the potential from the other eye, i.e., cross-talk.

We have performed studies to increase the accuracy of EOG. In conventional EOG, the potential difference between the medial and lateral canthi is measured, as shown in Fig. 1. We have reported that the eyeball can be analyzed as a battery model (10). In the battery model of the eye, the electrode potentials at the medial and lateral canthi are separately calculated, but we calculate the potential difference between them to be consistent with the con-

Received for publication November 26, 2007 ; accepted December 14, 2007.

Address correspondence and reprint requests to Kayo Shinomiya, Department of Ophthalmology and Visual Neuroscience, Institute of Health Biosciences, The University of Tokushima Graduate School, Kuramoto-cho, Tokushima 770-8503, Japan and Fax : +81-88-631-4848.

ventional method. However, in EOG recording, there are influences of the potential from the other eye called cross-talk. When there is a marked difference in the resting potential or ocular movements between the left and right eyes, cross-talk should be considered (11, 12). For the evaluation of cross-talk, not the potential difference between the medial and lateral canthi but the potentials of individual electrodes should be evaluated. As shown in Fig. 2, we placed negative electrodes on the body and positive electrodes at the medial and lateral canthi, measured their potentials separately, evaluated their characteristics, and analyzed cross-talk.

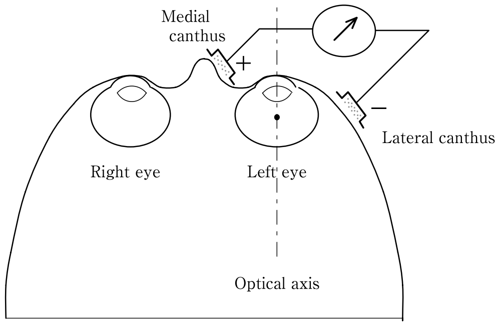


Fig. 1 Conventional EOG
The potential difference between the medial and lateral canthi is measured.

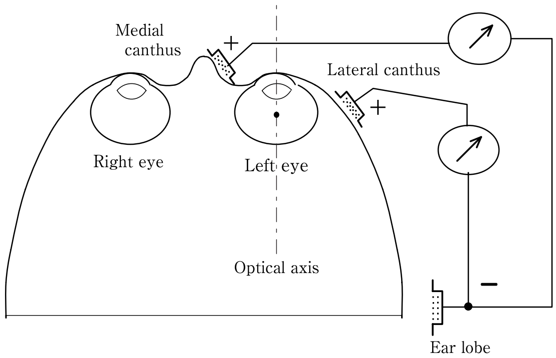


Fig. 2 Improved EOG
The potential of medial and lateral canthi is measured separately.

SUBJECTS AND METHODS

1. Subjects

To evaluate the characteristics of an improved EOG recording method, examination was performed in 6 healthy subjects without organic eye disorder other than refractive errors.

Subsequently, examination was performed in 6 adults (2 males and 4 females) with anophthalmia after unilateral enucleation due to various reasons. In all 6 subjects, the visual acuity in the normal eye was good, slit lamp biomicroscopy or funduscopy showed no abnormalities, and there was no history of operation. Table 1 shows the age, sex, side of anophthalmia, and its cause in each patient. Consent for cooperation was obtained from all subjects after explaining the purpose and contents of the study.

Table 1 Characteristics of subjects with unilateral anophthalmia

Case	Age	Sex	Side of anophthalmia	Cause
1	56	Female	Right	Trauma
2	65	Male	Right	Trauma
3	40	Female	Left	Retinoblastoma
4	66	Male	Left	Unknown
5	20	Female	Right	Glaucoma
6	73	Female	Left	Unknown

2. EOG recording method

Fig. 3 shows a scheme of the experimental system (13). We previously reported this system, but changed the sites of electrodes in this study, placing positive electrodes at the medial and lateral canthi and negative electrodes at the earlobes so that the potential from the body was zero. EOG potentials were obtained using silver-silver chloride disc electrodes (small-type bioelectrode, 12 mm : Nihon Kohden, Tokyo, Japan) attached to 4 sites of the medial and lateral canthi using paste. The negative electrodes were attached to the earlobes. The potential between the medial canthus electrode and earlobe was regarded as the medial canthus potential, and that between the lateral canthus electrode and earlobe as the lateral canthus potential. Detected potentials were amplified (time constant, 3.0 sec ; high cut, 10 Hz) using an alternating current amplifier (AN601G : Nihon Kohden, Tokyo,

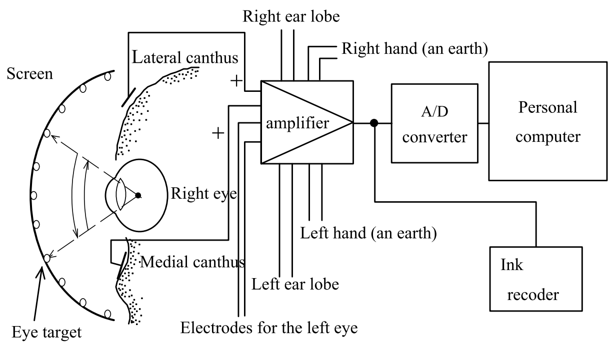


Fig. 3 Experimental system

Japan), passed through an A/D converter (resolution, 12 bits), transferred to a computer (PC9801 : NEC, Tokyo, Japan), and simultaneously recorded as analogue waves using an oscillographic recorder (Omniace RT3100, 4 channels : NEC San-ei Instruments, Tokyo, Japan).

In the experiment, 2 visual targets placed on a semi-cylindrical screen 50 cm in front of the eye were alternatively blinked at 1-second intervals, and potentials resulting from their tracking were measured. The eye movement angle ranged from 5° to 50° and was symmetrical.

3. Cross-talk calculation method

The cross-talk value was evaluated by comparing potentials between the electrodes. The characteristics of cross-talk were analyzed in terms of the ratio of the potential of the medial canthus electrode on the normal side to that of the medial /lateral canthus electrode on the anophthalmia side.

RESULTS

1. Measurement in healthy subjects

Fig. 4 shows EOG waves obtained when the subjects with bilaterally normal eyes moved each eye symmetrically (20° from the front). The horizontal and vertical axis represents time and EOG potential, respectively. At each angle, the potential at the medial was lower than that at the lateral canthus in the bilateral eyes. The polarity of waves at the lateral was reverse to that at the medial canthus in the bilateral eyes.

Fig. 5 shows a graph with eye movement angle on the horizontal and EOG potential on the vertical axes. In the figure, the right direction indicates plus, and the left direction does minus for ocular move-

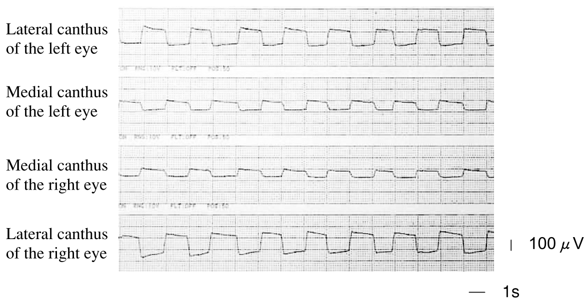
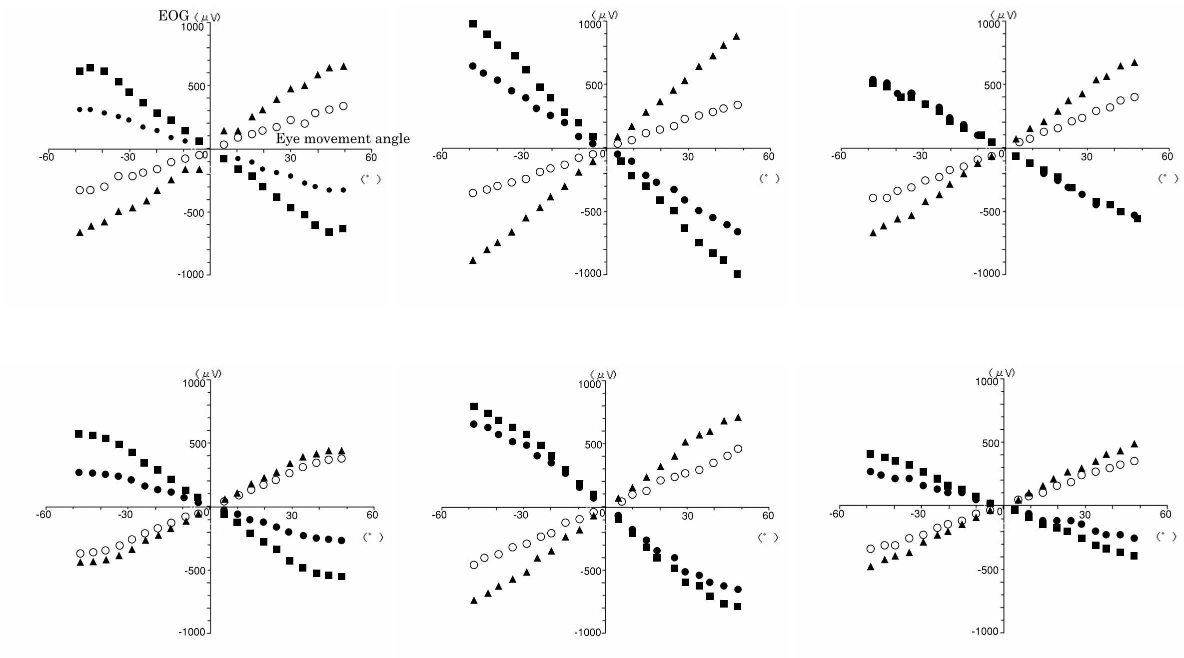


Fig. 4 EOG waves obtained when the subjects with bilaterally normal eyes moved each eye symmetrically (20° from the front).



Lateral canthus of the right eye ▲
Medial canthus of the right eye ●
Medial canthus of the left eye ○
Lateral canthus of the left eye ■

Fig. 5 6 subjects with bilaterally normal eyes ments. When attention is paid to the potentials of the medial and lateral canthus electrodes in the right eye, the potential detected at the medial was lower than that at the lateral canthus at each angle. In the left eye, similar findings were obtained. The polarity of the potential at the medial was reverse to that at the lateral canthus in the same eye. These findings are summarized as follows :

1. The potential detected at the medial was lower than that at the lateral canthus.
2. The polarity of the potential at the medial was reverse to that at the lateral canthus.

2. Measurement in subjects with unilateral anophthalmia

Fig. 6 shows EOG waves obtained when the subjects with right anophthalmia moved each eye symmetrically (50° from the front). Fig. 7 shows the results with right anophthalmia. The potential of the right lateral canthus electrode was very low and almost zero at an eye movement angle of ≤ 20°. The potential of the right medial canthus electrode was also low but higher than that of the lateral canthus. The polarity of the potential was the same between the medial and lateral canthi. These potentials are those from the left eye (cross-talk) since the right was an anophthalmia. In the normal left eye, the polarity of the potential at the medial was reverse to that at the lateral canthus. Other cases showed the same results. The results are summarized as follows :

1. On the anophthalmia side, the potential at the lateral was considerably lower than that at the medial canthus.
2. On the anophthalmia side, the polarity of the potential was same between the medial and lateral canthi.
3. On the normal side, the polarity of the potential at the medial was reverse to that at the lateral canthus.

3. Analysis of the characteristics of cross-talk

Table 2 shows cross-talk values during eye movements at 5° increments in angle. Since potentials

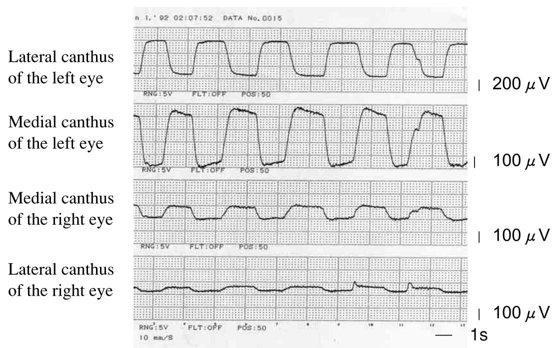


Fig. 6 EOG waves obtained when the subjects with right anophthalmia moved each eye symmetrically (50° from the front). (case 2)

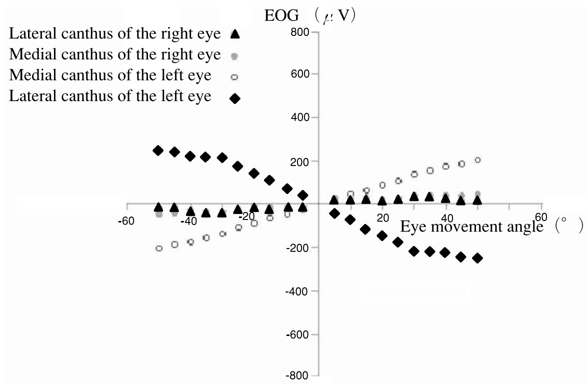


Fig. 7 Results with right anophthalmia (case 2)

Table 2 Cross-talk

Case	Eye movement angle 5	10	15	20	25	30	35	40	45	50	Average (30～50°)
	Potential of the medial canthus electrode on the anophthalmia side/ Potential of the medial canthus electrode on the normal side										
1	0.617	0.515	0.539	0.533	0.550	0.561	0.527	0.545	0.544	0.523	0.540
2	1.227	0.326	0.281	0.250	0.236	0.230	0.232	0.223	0.214	0.216	0.223
3	0.381	0.178	0.111	0.082	0.072	0.094	0.070	0.047	0.082	0.140	0.087
4	0.224	0.133	0.407	0.408	0.149	0.256	0.262	0.258	0.384	0.382	0.308
5	0.182	0.177	0.151	0.135	0.140	0.140	0.147	0.134	0.135	0.109	0.133
6	0.130	0.168	0.226	0.165	0.166	0.172	0.169	0.183	0.185	0.175	0.177
	Potential of the lateral canthus electrode on the anophthalmia side/ Potential of the medial canthus electrode on the normal side										
1	0.140	0.110	0.083	0.100	0.073	0.091	0.109	0.137	0.165	0.203	0.141
2	0.773	0.442	0.391	0.114	0.273	0.273	0.245	0.143	0.091	0.093	0.169
3	0.190	0.089	0.074	0.041	0.048	0.053	0.047	0.036	0.037	0.047	0.044
4	0.340	0.251	0.105	0.093	0.104	0.092	0.084	0.067	0.064	0.073	0.076
5	0.066	0.062	0.069	0.049	0.069	0.058	0.068	0.073	0.073	0.121	0.079
6	0.371	0.245	0.330	0.135	0.120	0.126	0.119	0.123	0.109	0.094	0.114

were low at an eye movement angle of ≤ 25°, causing marked errors in the ratio, the mean values from 30° to 50° are shown. The mean cross-talk to the medial canthus on the anophthalmia side was 0.087-0.540, i.e., 8.7%-54.0% of the potential at the medial canthus on the normal side. The mean cross-talk to the lateral canthus on the anophthalmia side was 0.044-0.169, i.e., 4.4%-16.9%.

DISCUSSION

Measurement in the normal subjects in this study showed a lower potential at the medial than at the lateral canthus. Since the medial canthus electrode was close to the cornea as the positive pole, we expected the potential of the medial to be higher than that of the lateral canthus electrode. However, the result was the reverse of this. This phenomenon cannot be simply explained using the conventional battery model of the eye. As a cause, the influence of cross-talk can be considered. Since the polarity of the potential at the medial canthus of the normal eye was reverse to that of the anophthalmia eye, there is a possibility that the potential is reduced due to cancellation by the influence of the other eye.

Cross-talk is the influence of the potential of the other eye and is also called the contralateral effect. Miles (1, 2) observed the influence of one eye to the other based on EOG records in 9 patients with anophthalmia. Imaizumi (14, 15), Ogita (16) and Kelsey (17), *et al*. also reported the influence of the potential of the other eye. Cross-talk presents few problems when bilateral eyes are normal. However, when there is a marked difference in the resting potential or eye movements between the left and right eyes, cross-talk can not be ignored in the analysis of fine movements and should be eliminated in EOG recording. The methods for the measurement and elimination of cross-talk were first reported by Thijssen (18), who reported a cross-talk of about 12% (-18.4 dB) in a unilateral eye movement method using convergence and about 16% (-16.0 dB) in a method for the evaluation of changes in the resting potential with the eyes placed in different adaptation situations. Kubo, *et al.* (11, 19) asked subjects to gaze at one point with one eye, measured the potential (cross-talk) in the fixed eye during forced adduction and abduction of the other eye by applying an aspiration contact lens, and also devised its elimination method. They reported that the mean value by their method was -16.4 dB. Itsuki, *et al.* (20) asked subjects to fix one eye on one point and measured EOG via multiple electrodes during forced adduction and abduction of the other eye using an aspiration contact lens. As the result, they observed the influence of the electrode site in the detection of contralateral EOG, and reported that the mean cross-talk was 17.8% (-15.0 dB) when the electrode was placed 20 mm temporal to the lateral canthus.

In previous studies, EOG was recorded merely as a potential difference between electrodes without consideration of the potentials of the electrodes themselves. We previously reported that the potential of each electrode can theoretically be calculated using a battery model of the eye and formula, and have compared the characteristics of potentials obtained using the theoretical formula and those of values obtained by measurement (10). The measurement and evaluation of the potential of each electrode allow the evaluation of changes in potential associated with eye adduction and abduction. As shown in Figs. 4 and 6, differences in the phase of waves can be clearly observed.

In this study, EOG was parallel to the eye movement angle until about 35°, but thereafter, showed a certain degree of saturation. Assuming that the eyeball can fully rotate in the horizontal plane, the potential theoretically reaches a peak when the eye is rotated by 90°, and becomes zero when it is rotated by 180°, bringing the cornea to the site of the retina. However, eye movements ≤ 50° are considered to be still linear. The saturation observed in this study may be because gazing at visual targets approaching the periphery of the visual field is difficult at a visual field angle of ≥ 40°. In this study, visual field angles > 40° were also included in the calculation of cross-talk because the calculation of the ratio presents no problems even if eye movements are inadequate.

The results of this study showed the marked influences of cross-talk on the potential at the medial canthus. Since the degree of influence was considerable (8.7%-54.0%), cross-talk in EOG analysis cannot be ignored. In contrast, the influence of cross-talk on the potential at the lateral canthus was slight. Therefore, in the analysis of cross-talk, attention only to the potential at the medial canthus is necessary for its calculation. When attention is paid to the potential at the lateral canthus, results with minimum errors due to cross-talk can be obtained.

The cross-talk value varies among subjects, due to the sites of attachment of electrodes (4) and individual differences (21). Further studies in which the sites of electrodes are clearly mentioned are necessary.

CONCLUSION

We recorded EOG by an improved method in normal subjects and patients with unilateral anophthalmia. This method allowed the evaluation of EOG characteristics according to electrodes and was useful for EOG analysis. The influence of cross-talk of the other eye was marked at the medial but slight at the lateral canthus. In EOG recording, results with minimum errors due to cross-talk can be obtained by paying attention to the potential at the lateral canthus.

ACKNOWLEDGMENTS

This study was supported in part by a Grant-in-Aid for Scientific Research (C) (No. 18500357) from the Japanese Ministry of Education, Culture, Sports, Science and Technology.

REFERENCES

1. Miles WR : The steady polarity potential of the human eye. Proc Nat Acad Sci 25 : 25-36, 1939
2. Miles WR : The steady potential of the human eye in subjects with unilateral enucleation. Proc Nat Acad Sci 25 : 349-358, 1939
3. Arden GB, Barrada A, Kelsey JH : New clinical test of retinal function based upon the standing potential oh the eye. Brit J Ophthal 46 : 449-467, 1962
4. Arden GB, Barrada A : Analysis oh the electro-oculograms of a series of normal subjects. Brit J Ophthal 46 : 468-482, 1962
5. Marg E : Development of electro-oculography, standing potential of the eye in registration of eye movement. Arch Ophthalmol 45 : 169-188, 1951
6. Ingster-Moati I, Bui Quoc E, Pless M, Djomby R, Orssaud C, Guichard JP, Woimant F : Ocular motility and Wilson's disease : a study on 34 patients. J Neurol Neurosurg Psychiatry 78 : 1199-1201, 2007
7. Melek NB, Blanco S, Garcia H : Electro-oculography of smooth pursuit and optokinetic nystagmus eye movements in type I Duane's retraction syndrome. Binocul Vis Strabismus Q 21 : 37-44, 2006
8. Mansour AM, Uwaydat SH, Chan CC : Long-term follow-up in Bietti crystalline dystrophy. Eur J Ophthalmol 17 : 680-682, 2007
9. Renner AB, Tillack H, Kraus H, Krämer F, Mohr N, Weber BH, Foerster MH, Kellner U : Late onset is common in best macular dystrophy associated with VMD2 gene mutations. Ophthalmology 112 : 586-592, 2005
10. Itsuki N, Kubo M, Shiraishi M, Nishikawa Y, Mimura Y : A battery model of the eyeball to calculate standing potential of the eye. J Jpn Ophthalmol Soc 99 (in Japanese) : 1012-1016, 1995
11. Kubo M, Hirai K, Mitsui Y : The measurement and elimination of Contralateral Effect(Cross-Talk) in EOG. Nihon Ganka Kiyo 30 (in Japanese) : 701-704, 1979
12. Shimooku J, Mimura O, Haruta R, Taoka N : How to read EOG. Neuro-ophthalmol Jpn 2 (in Japanese) : 129-133, 1985
13. Itsuki N, Kubo M, Shiraishi M, Nishikawa Y : Characteristics of the EOG potential changes generated by saccadic eye movements of large ampoitude. J Jpn Ophthalmol Soc 97 (in Japanese) : 514-518, 1993
14. Imaizumi K, Takahashi F, Toyama T, Horie E, Tazawa Y, Ogawa K, Shoji U : EOG in case of highly disturbed virsion. Rinshoganka 18 (in Japanese) : 333-344, 1964
15. Imaizumi K : The clinical application of electro-oculography(EOG). Proc 3rd ISCERG Symp. New York, 1966, pp.311-326
16. Ogita Y, Sotani T, Mimura O, Taniguchi I : Comparison of the amplitude of EOG depending on the eye position. Ganka Rinsho Iho 73 (in Japanese) : 943-946, 1979
17. Kelsey JH : The combined use of the EOG and ERG as a routine clinical procedure. Proc 6th ISCERG Symp. Leipzig, 311-326, 1966
18. Thijssen JM, Pinckers A : Contralateral effects in the electro-oculogram. Acta Ophthalmol 52 : 441-454, 1974
19. Kubo M, Itsuki N : Development of an automatic measuring and recording system for the EOG employing cross-talk feed-back cancellation. Nihon Ganka Kiyo 32 (in Japanese) : 1496-1500, 1981
20. Itsuki N, Kubo M, Nishikawa Y, Mimura Y, Nishihara M, Minamoto Y : Reducing cross-talk

in electrooculograms made with several electrodes. J Jpn Ophthalmol Soc 98 (in Japanese) : 251-257, 1994
21. Toyama T : Changes in the electro-oculogram by light and dark adaptation in case of pigmentary degeneration of the retina. J Jpn Ophthalmol Soc 66 (in Japanese) : 1517-1531, 1962