than input from the nondominant eye.[3] Therefore, ocular dominance may play an important role in temporal fluctuation in interocular blur suppression[4] (ie, the ability to suppress the blur image from 1 eye). For successful monovision, interocular blur suppression should flexibly change in each eye at all distances. Therefore, it is best that the ocular dominance in patients with monovision be as low as possible (ie, a high ocular dominance may cause severe stress in visual systems with monovision).

Binocular rivalry is not primarily viewed as a tool for measuring ocular dominance (sensory dominance) but rather for studying the neural correlates of visual perception. Binocular rivalry usually occurs with dissimilar images in each eye and is strongest when dissimilar contours are presented, such as with the presentation of orthogonally oriented grating images in each eye. This phenomenon is subject to the contrast of the images and is more likely to occur when both orthogonally oriented gratings are at high contrast.[5] Moreover, a visually stronger stimulus is less likely to be suppressed during rivalry and will be visible for longer than a weaker stimulus.[6] For example, 2 orthogonal gratings of equal contrast may be perceived alternately by each eye as visible for 50% of the time and suppressed for 50% of the time. However, if a high-contrast grating is presented to 1 eye and a low-contrast grating to the fellow eye, the high-contrast grating will be perceived more than 50% of the time and the low-contrast grating will be seen less than 50% of the time.

Ooi and He[7] designed a balance technique based on binocular rivalry and showed that directly adjusting the contrast intensity of the rivalry stimulus in each eye equalizes the percentage of dominance. They suggest that the quality of ocular dominance could be quantitatively evaluated using this balance technique. We developed a similar balance technique to quantitatively evaluate the quality of ocular dominance in dominant and nondominant eyes.[8] The technique demonstrates exclusive visibility and "reversal thresholds," which seem to be the best parameters for assessing the quality of ocular dominance.

Although monovision success in refractive surgery has been high,[9–12] it does not always occur. Further advancement requires elucidating the important factors in monovision success or a method of measuring patient satisfaction. Ocular dominance may be an important factor in the overall success of monovision.[1,7] Several reports have considered ocular dominance in relation to monovision success in presbyopic patients; however, no study has quantitatively investigated ocular dominance.[1,9,13,14]

In the present study, the quality of ocular dominance, induced by intraocular lens (IOL) implantation, was quantitatively investigated in patients with successful and unsuccessful monovision by our balance technique; the relationship between ocular dominance and the success of monovision was studied.

Patients and Methods

This study comprised 20 presbyopic patients who presented to the eye clinics at Kitasato University School of Medicine Hospital with bilateral cataract and who had monofocal IOL (AQ-110NV, Canon Staar) implantation. The patients, all of whom had best visual potential in both eyes, were offered the option of conventional monovision through monofocal IOL implantation (dominant eye corrected for distance and nondominant eye corrected for near). All patients gave informed consent, and the tenets of the Declaration of Helsinki were followed.

Patient Testing

The dominant eye was determined using a hole-in-card test (sighting dominance) in which the patients were asked to look at a Landolt C target at 50 cm and at 5 m through a 1 cm hole in the center of a piece of cardboard.

Patient satisfaction with monovision was quantitatively evaluated by a series of questions on satisfaction with distance- and near-vision functional ranges, the presence of asthenopia problems, depth-perception abilities, and overall satisfaction with monovision. Patients graded their satisfaction from 0 to 4 as follows: 0 = good; 1 = bad; 2 = worse; 3 = worst. The monovision patients were then divided into 2 groups: those who had a dissatisfaction value of 0 on all items (successful monovision group) and those who had a value greater than 1 (unsuccessful monovision group).

The ophthalmic orthoptic status, including stereopsis, was assessed using the Titmus stereo test and TNO random-dot stereo test.

Testing Procedures

Figure 1 shows the device used in the binocular rivalry balance technique.[8] Patients sat 50 cm from a display and were presented with rightward-tilted (45 degrees) and leftward-tilted (135 degrees) rectangular gratings in each eye. Targets were generated by a compiled program running on a PCG-XR9S personal computer (Sony) and were displayed on an RDF171S cathode-ray tube monitor (Mitsubishi). Vertically and horizontally, the displays measured 11.3 degrees.

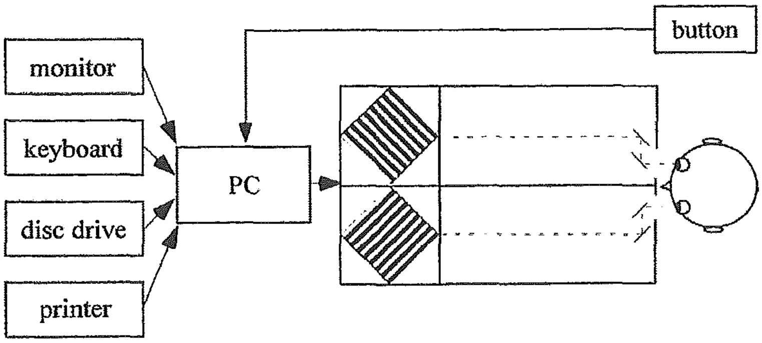


Figure 1. (Handa) Computer screen setup to test binocular rivalry.

Maximum and minimum luminance values of the targets were 110 cd/m^2 and 0.2 cd/m^2, respectively. The mean and background luminance values of the targets were 53.1 cd/m^2. An LS-100 photometer (Minolta) was used to calibrate the light output of the monitors.

The refractive power in both eyes was corrected for a focal distance at 50 cm using +2.0 diopter spherical lenses. Viewing was performed through uncorrected pupils, and the patient's heads was constrained with a chin rest and head rest. The inner surfaces of the box were painted flat black. Within the apertures for the patients' eyes were 2 mirrors in the front of the box for each eye, allowing horizontal shifting in either eye to facilitate fusion. Patients maintained fixation in approximately the center of the field and tracked fluctuations in the exclusive visibility of the 2 rival targets by pressing a computer button. Patients estimated the exclusive visibility as a general dominance of the trial target visibility compared with that of another target. Patients pressed the button when they determined the target to be dominant and released it when dominance was lost.

Patients had only to attend to exclusive visibility of 1 eye target (dominant- and nondominant-eye target) in several visibilities seen during binocular rivalry (ie, the exclusive visibility of the dominant-eye target, the exclusive visibility of the nondominant target, and the visibility of both dominant- and nondominant-eye targets) because the balance technique evaluates the total duration of exclusive visibility by 1 eye in the dominant and nondominant trials. Patients were not told the origin of binocular rivalry or which of their eyes was classified as dominant (hole-in-card test). The computer stored successive dominant durations of exclusive visibility. The durations were calculated as the total number of seconds the button was pressed during the 1-minute trial.

Targets were diamond-shaped patches of rectangular 2 cycles per degree (cpd) gratings that were 4 degrees in size. As data from a previous study[8] showed responses to this setting are stable and consistently evoked, this was used as the rivalry target. The contrast of the target in the dominant eye was varied (100% to 80% to 60% to 40% to 20%); the contrast in the nondominant eye was 100% in all trials. In the dominant-eye trials, patients were told to press the button when the target was exclusively visible as the target contrast varied. In the nondominant-eye trials, patients were told to press the button when the nondominant eye target was exclusively visible when the target was fixed at 100%. Each trial lasted 1 minute, with 1 minute between them. All trials were repeated 2 times.

Statistical Analysis

The qualities of ocular dominance were quantitatively evaluated as the reversal threshold at which exclusive visibility in the nondominant eye crossed over that of the dominant eye. The differences between the successful and unsuccessful monovision groups were evaluated by a Mann-Whitney *U* test. A *P* value of 0.05 was considered significant.

Results

The mean age of the 20 patients (7 men, 13 women) was 60 years (range 36 to 74 years). There were 16 patients in the successful monovision group and 4 in the unsuccessful monovision group. All patients were followed for more than 6 months after cataract surgery.

The general factors influencing monovision success, including age, sex, best corrected near and distance visual acuities, and stereopsis, did not differ significantly between the successful and unsuccessful monovision groups (Table 1). However, dissatisfaction values in the unsuccessful monovision group were significantly higher than in the successful monovision group (Table 2).

All patients recognized binocular rivalry regardless of the contrast in the dominant eye. Figure 2, *top*, and Figure 2, *bottom*, show the influence on exclusive visibility of varying contrasts in the dominant eye in the successful monovision group and the unsuccessful monovision group, respectively. In the successful monovision group, dominant-eye trials showed a general decrease in exclusive visibility with decreasing contrast in the dominant-eye target and a significant difference between the highest exclusive visibility at 100% and

Table 1. Postoperative characteristics of patients by group.

Characteristic	Successful Group (n = 16)	Unsuccessful Group (n = 4)	*P* Value
Mean age (y)	70 ± 11.9	58 ± 21.9	.15
Female, n (%)	10 (62.5)	1 (25.0)	.34
Right eye dominant, n (%)	14 (87.5)	1 (25.0)	.54
Mean IOL power (D)			
Dominant eye	18.5 ± 4.0	22.5 ± 4.4	.35
Nondominant eye	20.6 ± 4.0	20.8 ± 2.0	.68
Mean anisometropia (D)	2.28 ± 0.3	2.3 ± 0.2	.90
Mean distance BCVA (logMAR)			
Dominant eye	1.17	1.13	.44
Nondominant eye	1.20	1.20	>.99
Mean near BCVA (logMAR)			
Dominant eye	1.0	1.0	>.99
Nondominant eye (logMAR)	1.0	1.0	>.99
Stereopsis (s)			
TST test	142.8 ± 124.0	70.0 ± 2.6	.34
TNO test	140.0 ± 84.0	200 ± 69.0	.16

Means ± SD
BCVA = best corrected visual acuity

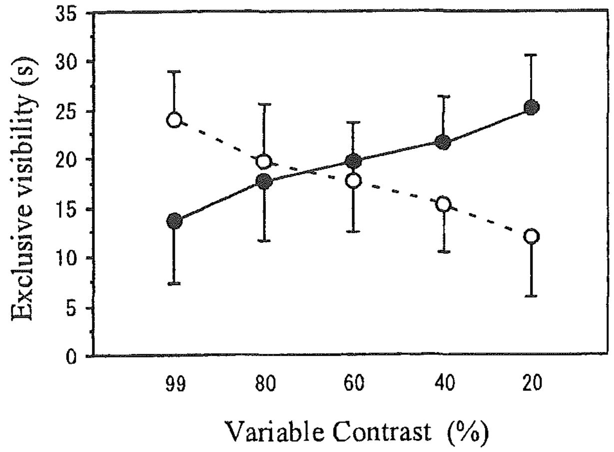
the lowest exclusive visibility at 20% in the dominant-eye target ($P<.05$). The nondominant-eye trials showed a general increase in exclusive visibility in the nondominant eye with decreasing contrast only in the dominant eye and a significant difference between the highest exclusive visibility at 20% and the lowest exclusive visibility at 100% in the dominant-eye target ($P<.05$).

In the unsuccessful monovision group, the dominant-eye trials showed a general decrease in exclusive visibility with decreasing contrast in the dominant-eye target and a significant difference between highest exclusive visibility at 100% and lowest exclusive visibility at 20% in the dominant-eye target ($P>.05$). The nondominant-eye trials showed a general increase in exclusive visibility in the nondominant eye with decreasing contrast only in the dominant eye and a significant difference between the highest exclusive visibility at 20% and lowest exclusive visibility at 100% in the dominant-eye target ($P>.05$).

Figure 3 shows the reversal thresholds (exclusive visibility of the nondominant eye crosses over that of the dominant eye) in the successful and unsuccessful monovision groups. The thresholds were displayed only at low decreasing contrasts of 80% and 60%. However, the reversal thresholds were revealed only at a high decreasing contrast of 20% or not at all (no reversal) in the unsuccessful monovision group. The reversal thresholds in the unsuccessful monovision group were

Table 2. Dissatisfaction values by group.

Question on Satisfaction	Mean ± SD: Successful Group (n = 16)	Mean ± SD: Unsuccessful Group (n = 4)	*P* Value
Distance and near vision	0	1.50 ± 0.57	<.001
Asthenopia	0	0.75 ± 0.50	<.001
Depth of perception	0	0.75 ± 0.50	<.001
Overall satisfaction	0	0.75 ± 0.50	<.001



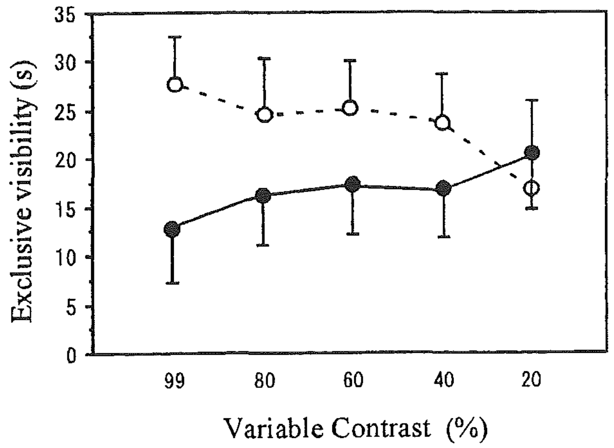


Figure 2. (Handa) Exclusive visibility by contrast level. *Top*: Exclusive visibility in the dominant eye in the successful monovision group. *Bottom*: Exclusive visibility in the dominant eye in the unsuccessful monovision group. The open circles and the dashed line represent exclusive visibility in the dominant eye, and the solid circles and solid lines represent exclusive visibility in the nondominant eye. The bar corresponds to the standard deviation.

at a lower contrast as the contrast decreased than those in the successful group. There was a significant difference in the reversal thresholds between the successful monovision group and unsuccessful monovision group ($P<.05$).

Discussion

Our study demonstrated the differences in the quantity of ocular dominance between patients with successful monovision and those with unsuccessful monovision. In patients with successful monovision, the reversal thresholds were obtained only at low decreasing contrasts of 80% and 60% in the dominant-eye target.

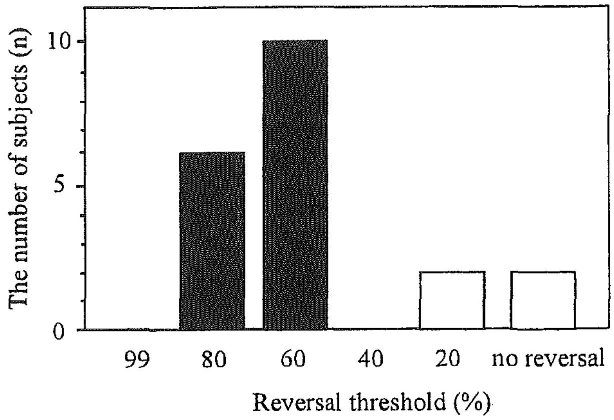


Figure 3. (Handa) Reversal thresholds. The black bars represent reversal thresholds in the successful monovision group and the white bars, the thresholds in the unsuccessful monovision group.

In contrast, in patients with unsuccessful monovision, the reversal thresholds were observed only at the decreasing contrast of 20% or not at all in the dominant eye. To guarantee the reliability of data for each patient, reversal thresholds were confirmed by obtaining 2 identical measurements. In all patients, the dominant eye for sensory dominance, determined by exclusive visibility, was the same eye determined to be the dominant eye in sighting dominance, indicated by a hole-in-card test. Ooi and He[7] developed the binocular rivalry balance technique, and we quantitatively applied the quality of ocular dominance examination in the dominant and nondominant eyes. Based on previous findings,[8] we clinically applied 2 cpd at 4 degrees in this study.

Ideal monovision requires alternating dominance and interocular blur suppression[4] (ie, the ability to suppress the blur image from 1 eye) for dependable distance vision. Therefore, strong dominance may render strong stress in visual systems, preventing alternating dominance and interocular blur suppression. Sippel and coauthors[9] indicate that strong sighting dominance is difficult to preserve in successful monovision; that is, weak sighting dominance (alternating dominance) seems to be an important factor in successful monovision. Since the reversal thresholds in patients with successful monovision in our study were at a higher contrast in the dominant eye than the reversal thresholds in patients with unsuccessful monovision, it is reasonable to consider that success and satisfaction in monovision patients are greatly influenced by the magnitude of ocular dominance. The dissatisfaction values of distance and near vision in the unsuccessful monovision group were twice that of the dissatisfaction values of other parameters, which agrees with the above hypothesis.

Another possibility is that reduced stereopsis has been considered to be the major disadvantage associated with monovision.[15] Jain and coauthors[1] found that patients with unsuccessful monovision had a reduction in stereopsis compared with patients with successful monovision. Our results did not show a disparity in a stereopsis examination at 40 cm between the successful and unsuccessful groups. However, based on the dissatisfaction score for depth of perception, all patients in the successful monovision group had good stereopsis at all distances. These results indicate that stereopsis plays an important role in the success of monovision.

Intraocular lens implantation for monovision may be advantageous in presbyopic patients having cataract surgery. However, this option should be pursued only after careful preoperative screening, especially examinations of the quantity of ocular dominance. Furthermore, our balance technique seems a practical method for evaluating the quantity of ocular dominance. In our clinics, we apply this technique for evaluating patients having cataract surgery who opt for monovision.

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Supported by the Academic Frontier Project of the Ministry of Education, Science, Sports and Culture, and Grant-in-Aid for Scientific Research No. 11835036, Ministry of Education, Science, Sports and Culture of Japan.

None of the authors has a financial or proprietary interest in any material or method mentioned.

1040-5488/04/8105-0377/0 VOL. 81, NO. 5, PP. 377–382
OPTOMETRY AND VISION SCIENCE

DOI: 10.1097/01.opx.0000135085.54136.65

ORIGINAL ARTICLES

Effects of Dominant and Nondominant Eyes in Binocular Rivalry

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ABSTRACT: *Purpose.* To investigate the relation between sighting and sensory eye dominance and attempt to quantitatively examine eye dominance using a balance technique based on binocular rivalry. *Methods.* The durations of exclusive visibility of the dominant and nondominant eye target in binocular rivalry were measured in 14 subjects. The dominant eye was determined by using the hole-in-card test (sighting dominance). In study 1, contrast of the target in one eye was fixed at 100% and contrast of the target in the other eye was varied from 100% to 80% to 60% to 40% to 20%, when using rectangular gratings of 1, 2, and 4 cycles per degree (cpd) at 2°, 4°, and 8° in size. In study 2, contrast of the target in the nondominant eye was fixed at 100% and contrast of the target in the dominant eye was varied from 100% to 80% to 60% to 40% to 20%, when using a rectangular grating of 2 cpd at 4° in size. *Results.* In study 1, the total duration of exclusive visibilities of the dominant eye target; that is, the target seen by the eye that had sighting dominance was longer compared with that of the nondominant eye target. When using rectangular gratings of 4 cpd, mean total duration of exclusive visibility of the dominant eye target was statistically longer than that of the nondominant eye target ($p < 0.05$). In study 2, reversals (in which duration of exclusive visibility of the nondominant eye becomes longer than the dominant eye when the contrast of the dominant eye target is decreased) were observed for all contrasts except for 100%. *Conclusions.* The dominant sighting eye identified by the hole-in-card test coincided with the dominant eye as determined by binocular rivalry. The contrast at which reversal occurs indicates the balance point of dominance and seems to be a useful quantitative indicator of eye dominance to clinical applications. (Optom Vis Sci 2004;81:377–382)

Key Words: binocular rivalry, exclusive visibility, eye dominance, sensory eye dominance, sighting eye dominance

Eye dominance has been evaluated by several methods since initial studies were performed to establish methods of assessment of eye dominance and the associated clinical implications.[1, 2] Evaluation methods for eye dominance can be divided into two major classes that are based on the presumed origin. The first method is based on motor origin eye dominance and is popularly known as sighting eye dominance and is determined by the hole-in-card test. Walls[3] defined this sighting eye dominance to be a one-eyed expression of an asymmetric but binocular phenomenon. The second method is based on eye dominance derived from a sensory origin; that is, sensory eye dominance that is preferred for a perceptual visual task that is related to the visual neural system. Berner and Berner[4] defined sensory eye dominance as the controlling eye in binocular perception, for example, that which can be determined by binocular rivalry. The difference between these definitions can lead one to hypothesize that sighting and sensory eye dominances are caused by different neural mechanisms. Moreover, several studies[5–8] have shown that sensory eye dominance could not predict motor eye dominance, and it is still unknown whether sighting and sensory eye dominances are caused by the same mechanism. Ocular dominance was documented by Hubel and Wiesel,[9] who reported finding ocular dominance columns within the primary visual cortex. Ocular dominance columns were even seen in primary visual cortex (V1) of a newborn and no visual experience animal.[10] However, ocular dominance columns of newborn animals are not specific separations of the right and left eye columns as seen in adult animals, and they have a large overlap between the right and left eye columns.[11] Separation into right and left eyes in overlap columns is greatly influenced by visual experience after birth. The sighting eye is established in early life and is stable[4, 12] by the middle of sensitive period in the visual development of humans. It is quite likely that the development of ocular dominance (ocular dominance columns) of the infant is greatly affected by the sighting eye in terms of visual experience. If ocular dominance (sensory dominance with origin in ocular dominance columns within the primary visual cortex) has been established by the influence of sighting eye dominance, we would greatly expect a relation between sighting and sensory eye dominance.

Binocular rivalry[13–15] is not primarily viewed as a tool for measuring sensory eye dominance, but rather as a tool for studying the neural correlates of visual perception. Binocular rivalry usually occurs with dissimilar images in each eye and is strongest when dissimilar contours are presented, such as with the presentation of orthogonally oriented grating images in each eye. This phenomenon is subject to the contrast of the images and is also more likely to occur when both orthogonally oriented gratings are of high contrast.[16] Moreover, a visually stronger stimulus is less likely to be suppressed during rivalry and, in fact, will be visible more often than a weaker stimulus.[17] For example, two orthogonal gratings of equal contrast may be perceived alternately by each eye as being visible for 50% of the time and suppressed for 50% of the time. However, if a high contrast grating is presented to one eye and a low contrast grating to the fellow eye, the high contrast grating will be perceived more than 50% of the time and the low contrast grating will be seen less than 50% of the time. Clinically, eye dominance evaluated by a hole-in-card test for sighting eye dominance is the most facile investigative tool of eye dominance. However, this test is unable to quantitatively evaluate eye dominance. Ooi et al.[8] designed a balance technique based on binocular rivalry and showed that by directly adjusting the contrast of a rivalry target in each eye, they could equalize the percentage of dominance. It was suggested that eye dominance could be quantitatively evaluated by using this balance technique. Because it is based on binocular rivalry that directly adjusts the contrast of orthogonal gratings in each eye, it can provide a comparison of exclusive visibility between dominant (i.e., target seen by the eye that had sighting dominance) and nondominant eye targets.

In the current study, we investigated the relation between sighting (hole-in-card test) and sensory (binocular rivalry) eye dominances and used a new balance technique based on binocular rivalry to quantitatively examine eye dominance.

MATERIALS AND METHODS

Subjects

Fourteen subjects (six men and eight women) between the ages of 19 and 23 years participated in the study. After all subjects had provided written informed consent, both eyes in each subject were measured. All participants had unremarkable ophthalmic examinations except for minor refractive errors in several subjects. None of the subjects used contact lenses. The dominant eye was determined using a hole-in-card test (sighting dominance) in which the subjects were asked to look at a Landolt C target at 50 cm and at 5 m through a 1 cm hole located in the center of a piece of cardboard.

Methods

Subjects sat in a darkened room at a distance of 50 cm from a display and were presented with rightward tilted (45°) rectangular gratings to the right eye and leftward tilted rectangular gratings (135°) to the left eye. Targets were generated by a compiled program running on a PCG-XR9S personal computer (Sony, Tokyo, Japan) and were displayed on an RDF171S cathode-ray tube (CRT) monitor (Mitsubishi, Tokyo, Japan). Vertically and horizontally, the displays measured 11.3°. A LS-100 photometer (Minolta, Tokyo, Japan) was used to calibrate light output of the monitors. Maximal and minimal luminance of the targets were 110 and 0.2 cd/m^2, respectively. Mean and background luminance for the targets was 53.1 cd/m^2.

Viewing was performed through natural pupils, and the subjects' heads were constrained with chin and head rests. Inner surfaces of the box were painted flat black. Within the apertures for the subjects' eyes were two mirrors in the front of the box for each eye, allowing horizontal adjustment in either eye to facilitate fusion. Subjects maintained fixation in about the center of the field and tracked fluctuations in the exclusive visibility of the two rival targets by pressing a computer button. Subjects estimated the exclusive visibility as a general dominance of the trial target visibility when compared with that of another target. Subjects pressed the button when the target was determined to be dominant and released it when dominance was lost. During a trial, subjects could perceive the exclusive visibility of the dominant eye target, the exclusive visibility of the nondominant target, and the visibility of both dominant and nondominant eye targets. Subjects had only to report the exclusive visibility of one eye target because the current balance technique evaluates total duration of exclusive visibility by each eye in the dominant and nondominant trials. We did not explain to the subjects the origin of binocular rivalry or which of their eyes had been classified as the dominant eye (hole-in-card test). The computer stored successive dominant durations of exclusive visibility. The durations were calculated as the total number of seconds the button was pressed during the 1 min trial.

Study 1: Effects of Dominant and Nondominant Eyes in Binocular Rivalry with Decreasing Contrast in One Target

Targets were diamond patches of rectangular gratings, and were 2, 4, and 8° in size. Spatial frequency varied in trials, ranging from 1, 2, and 4 cpd. Contrast of the target in one eye was varied from 20% to 100% in 20% steps, whereas that in the other eye was fixed at 100%. For the dominant eye trials, subjects were told to press the button when the dominant eye target (i.e., the target seen by the eye that had sighting dominance and in which the contrast was varied) was exclusively visible and the nondominant eye target was fixed at 100%. For the nondominant eye trials, subjects were told to press the button when the nondominant eye target (in which the contrast was varied) was exclusively visible and the dominant eye target was fixed at 100%. Each trial lasted 1 min and was followed by an intertrial interval of 1 min. All trials were repeated three times.

Study 2: Effects of Eye Dominance with Decreasing Contrast in the Dominant Eye Using 2 cpd with a 4° Target

Targets were diamond-shaped patches of rectangular 2 cpd gratings that were 4° in size, because data from study 1 showed responses to this setting were stable and consistently evoked. The contrast of the target in the dominant eye was varied from 20% to 100% in 20% steps, whereas that in the nondominant eye was fixed at 100% in all trials. For the dominant eye trials, subjects were told to press the button when the dominant eye target was exclusively visible, and the dominant eye target was varied from 20% to 100% in 20% steps. For the nondominant eye trials, subjects were told to press the button when the nondominant eye target was exclusively visible. All trials were repeated three times on a different day after study 1.

Data Analysis

The differences in measured target-related variations were evaluated by an analysis of variance (ANOVA). Measured contrast-related differences were evaluated by Friedman test, and the differences between the dominant and nondominant eye were evaluated by a Mann-Whitney U test.

RESULTS

Study 1: Effects of Dominant and Nondominant Eyes with Decreasing Contrast in One Target

All subjects could recognize binocular rivalry regardless of target size when using a spatial frequency of 1, 2, or 4 cpd, and they could recognize binocular rivalry regardless of the varying contrast. Variations on the total duration of exclusive visibility with regards to varying contrast are shown separately in graphs plotting the three target sizes and spatial frequencies (Fig. 1).

Dominant eye trials showed a small change in the total duration of exclusive visibility with decreasing contrast in dominant eye targets (i.e., the target seen by the eye that had sighting dominance). The total duration of exclusive visibility at 20% tended to be somewhat shorter than that at 100%. However, these variations in the total duration of exclusive visibility were not statistically significant (ANOVA, $p > 0.05$). Nondominant eye trials showed a small change in the total duration of exclusive visibility with decreasing contrast in dominant eye targets, with minor fluctuations. These variations for the total duration of exclusive visibility were not statistically significant (ANOVA, $p > 0.05$). The total duration of exclusive visibility of the dominant eye target was longer than that of the nondominant eye target. When using rectangular gratings of 4 cpd targets, mean total duration of exclusive

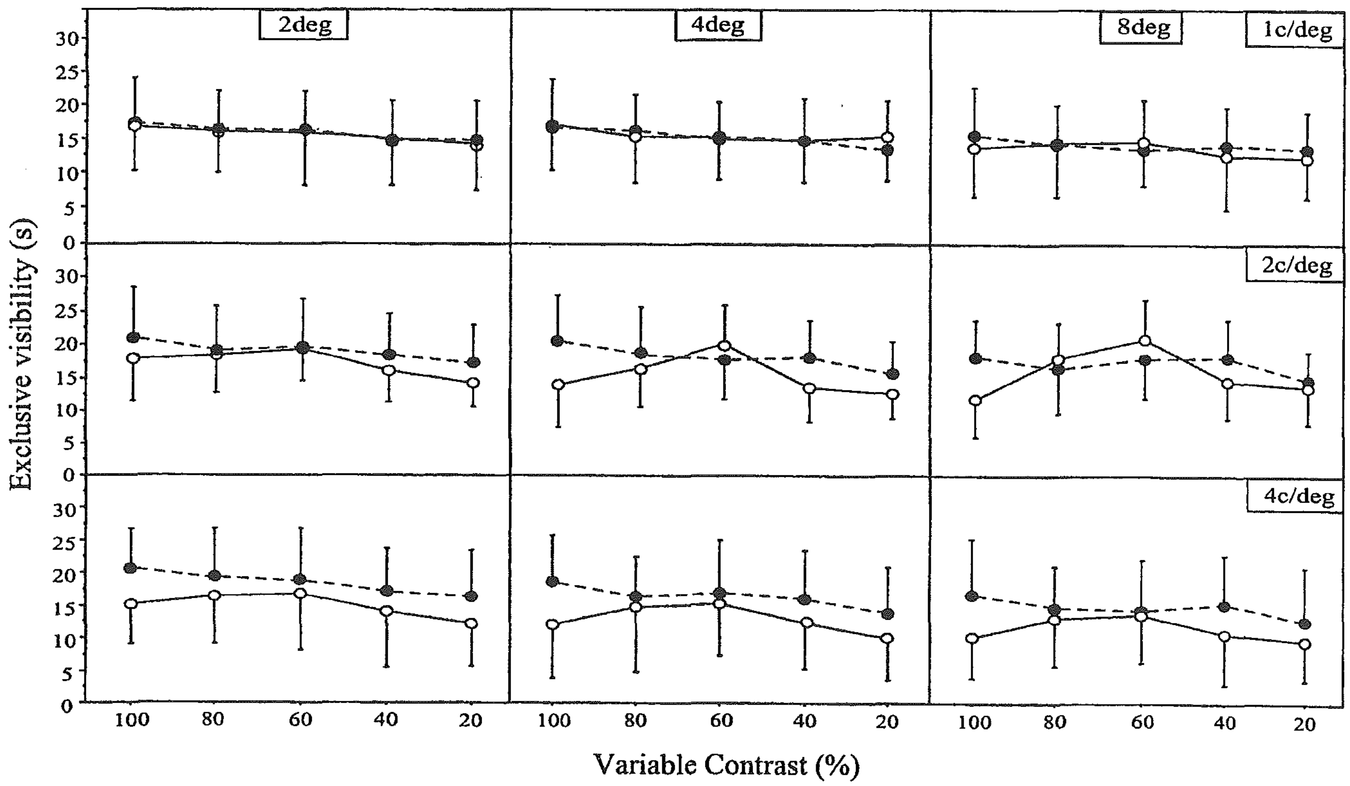

FIGURE 1.
The total duration of exclusive visibility with decreasing contrast are shown for three spatial frequencies (1, 2, and 4 cpd) and three target sizes (2, 4, and 8°). Solid circles and dashed lines represent the total duration of exclusive visibility of the dominant eye target, and open circles and solid lines represent the duration of exclusive visibility of the nondominant eye target. For dominant and nondominant eye trials, contrast for the other eye target was fixed at 100%. Bars correspond to standard deviations (SD). When using a rectangular grating of 4 cpd, a statistically significant difference in the mean total duration of exclusive visibility between the dominant and nondominant eye targets was found (Mann-Whitney U test, $p < 0.05$).

visibility of the dominant eye target was significantly longer than that of the nondominant eye target (Mann-Whitney U test, $p < 0.05$).

Study 2: Effects of Eye Dominance with Decreasing Contrast in the Dominant Eye Using 2 cpd with 4° Targets

All subjects could recognize binocular rivalry regardless of the varying contrast of the dominant eye when using 2 cpd with 4° targets. Variations in the total duration of exclusive visibility with regards to varying contrast of the dominant eye target are shown in Fig. 2A. Dominant eye trials identified a general decrease in the total duration of exclusive visibility with decreasing contrast in the dominant eye target, and these decreases for the total duration of exclusive visibility were statistically significant (Friedman test, $p < 0.05$). In contrast, for the nondominant eye trials, a general increase was observed in the total duration of exclusive visibility of the nondominant eye with decreasing contrast in the dominant eye target, and these increases for the total duration of exclusive visibility were statistically significant (Friedman test, $p < 0.05$). At 100% contrast of the dominant eye target, the total duration of exclusive visibility of the dominant eye target was longer than that of the nondominant eye target (Mann-Whitney U test, $p < 0.05$). At 20% contrast of the dominant eye target, the total duration of exclusive visibility of the nondominant eye target exceeded the total duration of exclusive visibility of the dominant eye target (Mann-Whitney U test, $p < 0.05$).

Reversals were defined as the point at which the total duration of exclusive visibility of the nondominant eye target became longer than that of the dominant eye target, as contrast to the dominant eye was decreased and varied between 20% and 80% contrast, depending on the subject (Fig. 2B).

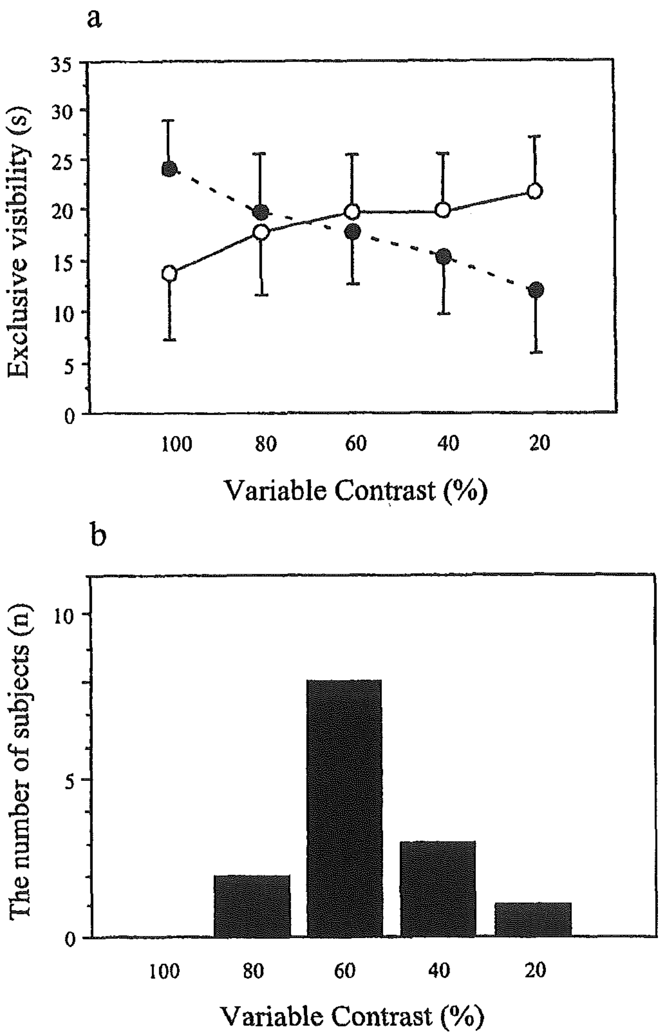

FIGURE 2.
A: The total duration of exclusive visibility seen with decreasing contrast in the dominant eye is shown for the 2 cpd at 4°. Solid circles and dashed lines represent the total duration of exclusive visibility of the dominant eye target, and open circles and solid lines represent the total duration of exclusive visibility of the nondominant eye target. In the dominant and nondominant eye trials, contrast in the nondominant eye was fixed at 100%. Bars correspond to standard deviation (SD). B: Data for the reversals, where the total duration of exclusive visibility of the nondominant eye target exceeded that for the dominant eye target, are shown for 2 cpd at 4°.

DISCUSSION

The most important findings in this study were the observation of an equivalence of sighting eye dominance, identified by the hole-in-card test, and sensory eye dominance, determined by binocular rivalry, and our balance technique based on binocular rivalry could quantitatively evaluate eye dominance. To guarantee the reliability of the data for each subject, exclusive visibility was confirmed as being identical in three repeated measurements and studies 1 and 2 on different days.

The balance techniques based on binocular rivalry have previously been shown to be able to equalize the sensory dominance in each eye by using the addition of neutral density filters in front of the dominant eye.[17, 18] Recently, Ooi et al.[8] designed an original balance technique that directly adjusted the contrast of rivalry stimulus in each eye to achieve equal percentage of sensory dominance, instead of adding neutral density filters. Moreover, the present balance technique has an advantage over these previous balance techniques in several aspects, for example, the elimination of the inclination for one target (rightward tilted or leftward tilted rectangular gratings) per subject, the elimination of the bias of visual attention toward one target over another, and an easy response for determining the perception of exclusive visibility, because the present balance technique evaluates the total duration of exclusive visibility by one eye (through the use of separate dominant and nondominant eye trials). Thus, sensory eye dominance determined in the current study appears to be more reliable than that captured by previous studies. In our studies, a fluctuation in perception between dominant and nondominant eye targets is evaluated as dominant duration of one eye target, because dominant duration is likely to be perceived more easily than suppression duration.

Previously, there have been reports on the relation between sighting and sensory eye dominance.[5–8, 19] Blake et al.[19] inferred that there was a relation for sighting and sensory eye dominance during binocular rivalry. Moreover, Porac et al.[20] reported that dominant periods during binocular rivalry of the sighting eye were longer than that of the nonsighting eye, although they did not use sophisticated methods applying various contrasts, spatial frequencies and sizes, or our balance technique method. Conversely, other studies[5–8] support the opposite viewpoint (i.e., sensory eye dominance cannot predict sighting eye dominance). Our results show equivalence of the sighting shown by longer exclusive visibility in the dominant eye trials and the sensory eye dominances and did not show any discrepancies between the sighting and the sensory eye dominance, similar to the findings of Ooi et al.[8] and other investigators.[5–7] In the study by Ooi et al., they did not measure exclusive visibility in separate dominant and nondominant eye trials and they also used different methodologies (i.e., color, spatial frequency, and multiple targets) and a different retinal location of the rivalry target in displays. Moreover, Dengis et al.[12, 21] reported that sighting dominance determining by the hole-in-card test developed from the center of visual direction for egocenter localization until 5 years old. Thus, the controversy over equivalence of sighting and sensory eye dominances remains unresolved.

In the current study, only when using a rectangular grating of 4 cpd was the mean total duration of exclusive visibility in the dominant eye target significantly longer than that of the nondominant eye target. Blake[22] reported that the contrast sensitivity function in binocular rivalry is similar to that in monocular viewing, with a peak at middle spatial frequency rivalry targets of about 4 cpd. Moreover, Movshon et al.[23] reported that loss of sensitivity is apparent at middle to high spatial frequencies in amblyopic eyes,[24] but not at spatial frequencies below 2 cpd. These findings are consistent with our result that the difference between the dominant and nondominant eye in low spatial frequencies targets at 1 and 2 cpd are not very marked. In other words, the difference between the dominant and nondominant eye is seen at spatial frequencies of 4 cpd or higher.

Until now, eye dominance has not been quantitatively investigated. However, eye dominance can be distinguished based on the dominance of visual function. If the dominance of the dominant eye in binocular rivalry is decreased by directly adjusting the intensity of the rivalry target in the dominant eye, our balance technique may be able to quantitatively evaluate eye dominance. Our study quantitatively examined eye dominance with techniques that documented items such as reversals in the exclusive visibility of the nondominant eye target (study 2). In the visual system, adjusting the intensity of rivalry targets, similar to that seen in our studies, exerts a great influence on the duration of suppression, with little effect on the duration of dominance.[25] Suppression phases in binocular rivalry might be accompanied by temporary distributions in temporal patterning of activity in populations of neurons in the primary visual cortex (V1).[26] Moreover, Sengpiel et al.[27] physiologically reported that switching dominance and suppression during binocular rivalry occurs between each eye's ocular dominance columns in V1. Recently, several fMRI studies[28, 29] confirmed that neuronal events in binocular rivalry occur in V1 and nearby visual areas. Moreover, Polonsky et al.[29] reported that activity in V1 increased when a subject perceived the higher contrast pattern and decreased when the subject perceived the lower contrast pattern. Hence, it presumed that the reversals in study 2 have represented a point at which suppression duration of the sighting dominant eye is longer than that of the nondominant eye in V1 and associated visual cortex.

An important clinical finding shown by the current study was the large individual variation seen in the quantity of eye dominance. Berner and Berner[4] suggested that sensory eye dominance could be shifted with changes in or training of vision and implied there was a plasticity of eye dominance. Eye dominance appears to be determined by adaptability from neurological plasticity. Therefore, it is not surprising that there is large individual variation in the quantity of eye dominance. These findings are consistent with our assumption that the current balance technique may be applicable for use in estimating the magnitude of eye dominance.

Our study may provide evidence of equivalence of sighting and sensory eye dominance, and our balance technique seems to be a practical method for the evaluation of the quantity of eye dominance. Recently, monovision in refractive surgery has been widely used in presbyopic patients.[30–33] Eye dominance may be one of the important factors in monovision success.[5, 34] Several reports[30, 34–36] have considered eye dominance in relation to monovision success in presbyopic patients; however, no studies have quantitatively investigated eye dominance. Hence, our balance technique appears to be a useful practical method for evaluation of the quantity of eye dominance. Further studies are needed to clarify the role of ocular dominance columns in the primary visual cortex between sensory and sighting dominance.

ACKNOWLEDGMENTS

Supported by the Academic Frontier Project of the Ministry of Education, Science, Sports and Culture, and Grant-in-Aid for Scientific Research no. 11835036 from the Ministry of Education, Science, Sports, and Culture of Japan.

Received January 9, 2003; accepted January 18, 2004.

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眼内レンズによるモノビジョン法の視機能評価

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目 的：白内障術後の調節機能消失への対策として，眼内レンズによるモノビジョン法が挙げられる．今回，眼内レンズによるモノビジョン法の視機能および満足度の評価を行った．**方 法**：対象は，眼内レンズによるモノビジョン法を施行した69例である．全例，hole in the card testを用い決定した優位眼を遠見，非優位眼を近見に矯正した．視機能評価には，全距離視力，コントラスト感度，近見立体視を用いた．満足度の評価は，術後アンケートで行った．**結 果**：術後平均屈折差は，2.29（1.5〜3.5）Dであった．両眼開放視力は，ほとんどの症例ですべての距離において0.8以上の値を示し，特に0.7および1mの距離においては，単眼視力より2段階以上の上昇を示した．コントラスト感度では，低〜中空間周波数領域のみに両眼加算が認められた．近見立体視では，100秒以下の症例は全体の55％であった．アンケートの結果，全症例の75％に満足が得られ，術後眼鏡使用率は17％と低い値を示した．**結 論**：眼内レンズによるモノビジョン法は，白内障術後の調節機能消失への対策として有用な方法の一つであると考えられた．

Assessment of Visual Function in Pseudophakic Monovision

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Purpose：Recently, monovision correction has been used for the treatment of presbyopia in patients with loss of accommodation after cataract surgery. We investigated visual function and acceptability of pseudophakic monovision in these patients. **Methods**：The study included sixty-nine patients with pseudophakic monovision. Ocular dominance was determined by the "hole in the card test". The dominant eye was corrected to be emmetropic and the non-dominant eye was corrected to be myopic. Visual acuity at various distances, contrast sensitivity and stereoacuity at near were measured. Subjective satisfaction was evaluated by a questionnaire. **Results**：The mean difference in spherical equivalent refractive error between the two eyes was 2.29D (range 1.5 to 3.5D). Most patients had a binocular uncorrected visual acuity of 20/25 or better at all distance. In particular, at middle distances (0.7 and 1 m), the binocular visual acuity was two or more lines better than the monocular visual acuity. With contrast sensitivity testing, binocular summation was observed at 0.5 to 2.0 cycles per degree. Stereopsis at near was less than or equal to 100 seconds in 55% of patients. Satisfaction was obtained in 75% of patients, and dependence on optical aids after surgery occurred for just 17% of patients. **Conclusion**：Pseudophakic monovision may be an effective way to manage loss of accommodation after cataract surgery.

[Japanese Journal of Ophthalmic Surgery 17(2)：223-228, 2004]

I 緒 言

いわゆる老視とよばれる加齢に伴う調節力の減退は40歳代前半より自覚することが知られており，その要因として，水晶体の硬化や水晶体容積の増大が推察されている[1〜3]．その対処法としては，国内では眼鏡による矯正が一般的であるが，欧米では両眼の屈折度数に差をつけ，一眼を遠見用に，他眼を近見用に矯正するモノビジョン法が古くより行われている．モノビジョン法はコンタクトレンズによる矯正[4〜9]が一般的であるが，近年，屈折矯正手術[10〜13]にも応用される

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ようになってきた．

一方，白内障手術においても，術後の調節機能消失はいまだ避けられない問題であり，筆者らは，白内障手術時にモノビジョン法を取り入れることにより，術後の調節機能消失への対策のほか，今後の老視治療の糸口になると考え，1999年より眼内レンズによるモノビジョン法を施行し，高い満足度を得てきた[14]．しかし，眼内レンズによるモノビジョン法の視機能についての報告は非常に少ない[14~17]．

今回，筆者らは眼内レンズによるモノビジョン法の中間距離を含む全距離視力，コントラスト感度，両眼視機能などの視機能評価を行ったので報告する．

II 対象および方法

眼内レンズによるモノビジョン法の適応は，白内障以外の器質的眼疾患を有するまたは発症の可能性がある症例，角膜乱視1.5D以上の症例を除外し，さらに十分なインフォームド・コンセントが得られた症例のみを図1に示すフローチャートに従い決定した．

眼優位性の検査には，大型弱視鏡用に独自に作成した異質図形（視角1度，コントラスト100％，空間周波数3.0 cpd）を用い，視野闘争を誘発させ，両眼ともほぼ同等に誘発される場合を「眼優位性が弱い」，一眼に抑制がかかる場合を「眼優位性が強い」と判定した．なお，術前の視力に自覚的左右差のある症例では，検眼枠に遮閉膜[18]（Bangerter filter；Ryser社）を貼り自覚的に左右同一にみえる状態にしたうえで術前の両眼視機能や眼優位性の判定を行った．

白内障手術は，点眼麻酔下，耳側角膜2.6 mm切開の超音波乳化吸引術後，同創口よりインジェクターを用い眼内レンズ（AQ-110NV，Canon-Staar）の挿入を行った．その際に，術前に hole in the card test を用いて決定した優位眼[19]を正視に矯正し，非優位眼を術後屈折が－2～－2.5Dになるように眼内レンズ度数を選択した．

対象は，1999年5月より2002年9月までに北里大学病院で両眼の白内障手術時に眼内レンズによるモノビジョン法を施行した症例のうち，優位眼の遠見裸眼視力が1.0以上，非優位眼の近見裸眼視力が0.6以上，術後3カ月以上経過，術後乱視1.5D未満の条件を満たした男性14例，女性55例の計69例（以下，モノビジョン群）である．モノビジョン群の平均年齢は67歳（29～85歳），平均観察期間は13カ月（1.6～35カ月）である．

さらに，同時期に両眼の白内障手術を施行し，術後屈折が両眼正視の男性19例，女性23例の計42例（以下，両眼正視群）を比較対象とした．両眼正視群の平均年齢は67歳（44～87歳），平均観察期間は8カ月（2～13カ月）である．

1. 全距離視力の測定

全距離における視力測定は，全視能域・全距離視力測定計

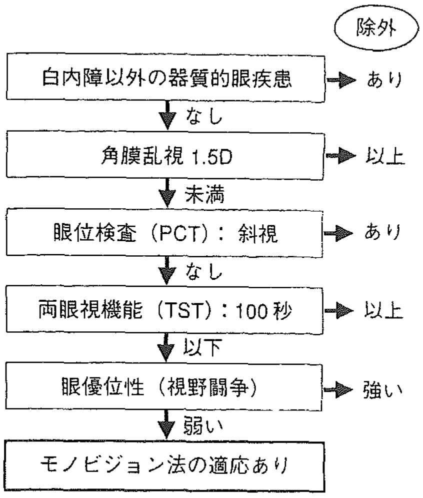

図1 眼内レンズによるモノビジョン法の適応基準

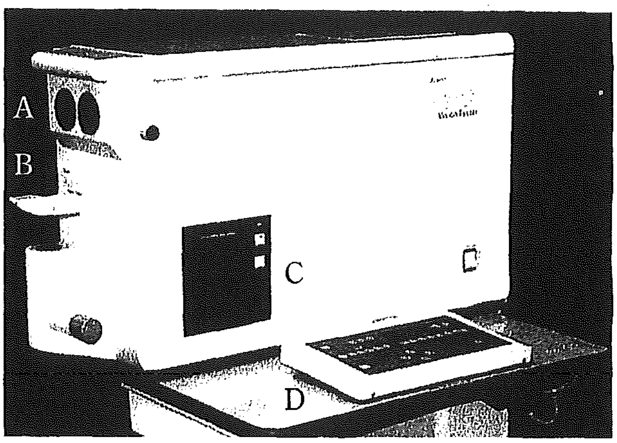

図2 全視能域・全距離視力測定計（AS-15）
A：接眼部，B：顎台，C：プリンター，D：コントロールパネル．

AS-15（興和社）（図2）を用い，非屈折矯正下で両眼開放および単眼視力をそれぞれ，0.3，0.5，0.7，1，3，5 mの6点で行った．平均視力の算出には，log MAR視力換算値を用いた．

2. コントラスト感度の測定

コントラスト感度の測定は，パーソナルコンピューターを用いたコントラスト感度測定装置[20]を用い，非屈折矯正下で両眼開放および優位眼単眼視下で行った．測定は，準暗室下，1.27 mの距離で行い，0.5から16 cpdまでの各空間周波数領域のコントラスト閾値をランダムに5回ずつ測定し，その平均値を用いた．また，網膜照度や瞳孔径の影響を一定にするため，両眼開放下で測定後，5分間の間隔をとり優位眼単眼で測定を行った．

3. 近見立体視の測定

近見立体視の検査には，Titmus stereo test（TST）を用

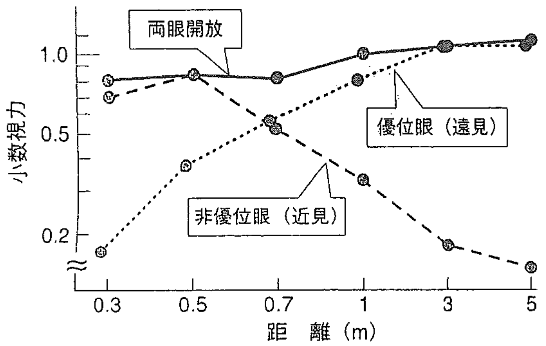

図3　モノビジョン群の全距離視力

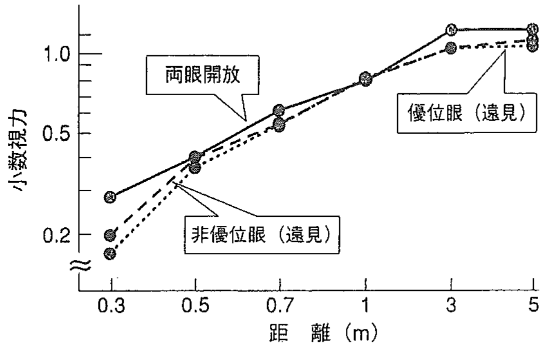

図4　正視群の全距離視力

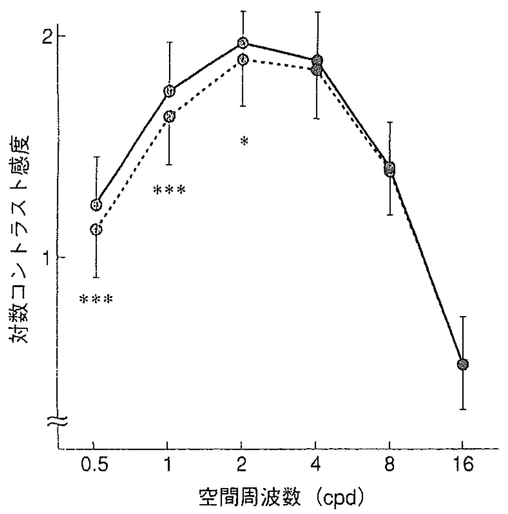

図5　モノビジョン群のコントラスト感度
実線は両眼開放視下，点線は優位眼単眼視下を示す．
*：p＜0.05，***：p＜0.0001．

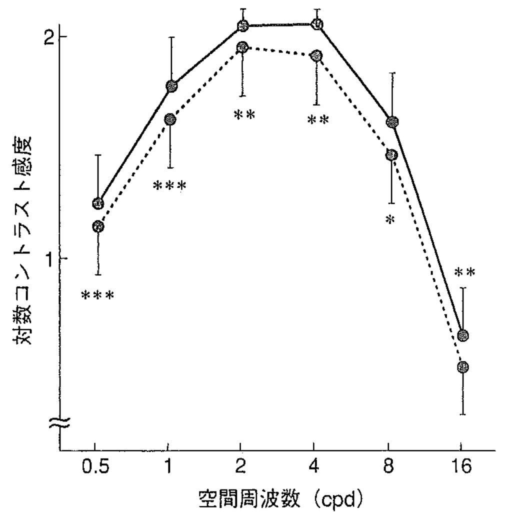

図6　正視群のコントラスト感度
実線は両眼開放視下，点線は優位眼単眼視下を示す．
*：p＜0.05，**：p＜0.01，***：p＜0.0001．

い，評価にはTitmus circle testの結果を採用した．測定は両眼非屈折矯正下および近見完全矯正下で距離40 cmで行った．

4.　術後満足度の評価法

満足度の評価を「左右のバランスについての違和感」「駅の時刻表や運転時などの遠方の見え方」「足元やテレビなどの中間距離の見え方」「読書など近方の見え方」「術後眼精疲労の出現」「眼鏡の使用の有無」の項目につき，アンケート形式で行った．その回答より，まったく不都合のない症例を「高満足」，1項目でも強い不都合を感じるまたは2項目以上の軽度の不都合を感じる症例を「不満足」，その他を「満足」の3段階に評価した．さらに，術前の屈折を±0.50D以下を正視とし，術前の左右眼の屈折と満足度の関係につき検討した．

III　結　　果

モノビジョン群の術後平均屈折は，優位眼では0.13D（−0.50〜1.00D），非優位眼では−2.18D（−1.5〜−3.75D），屈折差は2.29D（1.5〜3.5D）であった．

1.　全距離視力

両群の結果を図3および図4に示した．モノビジョン群では，両眼開放裸眼視力の平均は，いずれの距離においても0.8以上であり，特に中間距離（0.7，1 m）においては単眼視力より2段階以上の良好な視力が得られた．両眼正視群との比較では近方から中間距離で明らかな差を認めた．

2.　コントラスト感度

両群のコントラスト感度の結果を図5および図6に示した．正視群では，全空間周波数領域において両眼加算（binocular summation）が認められたのに対し，モノビジョン群では，0.5〜2 cpdの低〜中空間周波数領域のみに両眼加算が認められ，4 cpd以上の高空間周波数領域では両眼加算は認められなかった．

3.　近見立体視

近見立体視は，両眼非屈折矯正下では中央値は80秒であ

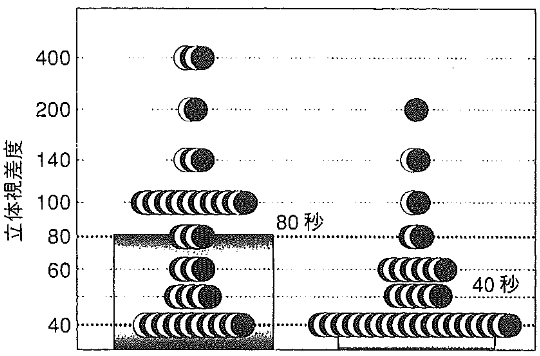

図7　モノビジョン群の近見立体視
バーは中央値，●は実測値の分布を示す．

り，全体の55％（38例）は100秒以下であった．両眼近見完全矯正下では，中央値は40秒であり，100秒以下の症例は全体の95％（59例）であった（**図7**）．

4．術後満足度

術後アンケートの結果は，高満足45％（32例），満足30％（20例），不満足25％（17例）であった（**図8**）．不満足であった症例の回答内訳を**表1**に示した．眼鏡使用率においては，正視群では全体の74％（18例）の症例で遠方，近方のいずれかまたは両方の眼鏡が必要であったが，モノビジョン群では眼鏡を必要とした症例は全体の17％（9例）のみと両群の差は明らかであった（**図9**）．また，満足であった症例の術前の屈折の組み合わせは，正視と近視または遠視と近視が最も多く，術前に屈折差が少ない症例の割合は低かった（**図10**）．

Ⅳ 考　按

初期老視を対象としたコンタクトレンズや屈折矯正手術によるモノビジョン法では，残余調節力があるため必要な屈折差は約1～2Dである[13]．しかし，眼内レンズによるモノビジョン法では，残余調節力がないため，遠方から近方まで良好な視力を得るには，より大きな屈折差（2～2.5D）が必要であり[14]，屈折度数の変更も容易ではない．そのため，眼内レンズによるモノビジョン法ではより適応を慎重に選択しなければならない．

今回の対象は，十分なインフォームド・コンセントが得られ，白内障手術時に眼内レンズによるモノビジョン法を選択した症例である．インフォームド・コンセントには，眼鏡装用なしで遠見から近見までの良好な視力が期待されるが，術後屈折誤差を生じた場合は遠方から近方まで十分な視力が得られないこと，意図的に左右眼に屈折差をつけるため不同視による違和感や両眼視機能の低下を起こす場合があることも説明する必要がある．具体的には，テニスなどのスポーツの際に遠近感がとりにくくなることや夜間の対向車のヘッドライトなどは見えにくいため，夜間の運転には支障が生じることがあることを説明している．また，このように適応しなかった症例に対しては，眼鏡装用以外に眼内レンズ交換やレーザーによる追加屈折矯正手術などの手段があることをあら

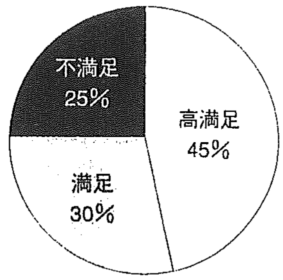

図8　術後アンケートによる満足度

表1　不満足症例の術後アンケート結果（n＝17）

●近方視不良	10（59％）	●違和感	7（41％）
●術後眼精疲労	10（59％）	●遠方視不良	7（41％）
●眼鏡使用	9（53％）	●中間視不良	6（35％）

複数回答である．

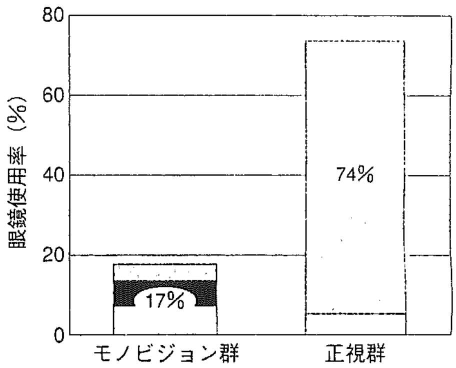

図9　術後眼鏡使用率（モノビジョン群 vs 正視群）
□：近方，■：遠方，□：両用．

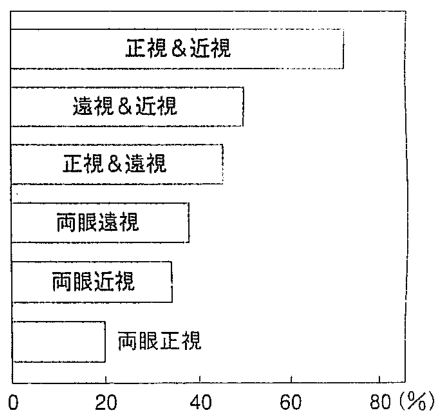

図10　術前屈折と術後満足度

じめ十分に説明している．白内障以外の器質的眼疾患を有する症例や発症の可能性がある症例は，単眼での十分な視力や良好な両眼視機能が得られないためあらかじめ適応から除外した．また，特に遠方に矯正した優位眼の斜乱視は著しく両眼開放視力を低下させることから[5]，強度角膜乱視を有する症例も適応から除外し，惹起乱視に十分留意し手術を行っている[21]．

さらに，適応決定のための術前検査として，眼位検査(Hirschberg 法，プリズム遮閉試験)，両眼視機能検査(TST)，眼優位性判定（視野闘争）を行った．

眼優位性（ocular dominancy）を構成するさまざまな要素は、sensory，sighting，acuity の3つに大別することができる[21]．眼優位性の定性には視野闘争を用いて，「より長く知覚する眼」(sensory dominance）で評価した．モノビジョン法の成功には，一眼のボケの抑制（blur suppression）の良否が重要となるが[6~8]，眼優位性（sensory dominance）の強い症例では，このボケの抑制が十分に機能しないことから[4,8]，モノビジョン法には不適応と考え適応から除外した．また，優位眼を遠見矯正にする方法が一般的であり[4]，当教室における正常者にコンタクトレンズを用いて行ったモノビジョン法の基礎研究でも，優位眼遠見矯正のほうが非優位眼遠見矯正に比較して，近見立体視やコントラスト感度の両眼加算が良好であったことより，hole in the card test を用い決定した優位眼[19]，つまり単眼視を強いる条件下で習慣的に使用する眼（sighting dominance）を遠見矯正とした．

全距離視力測定に用いた視力計は，Badal optometer として知られる原理を利用している．この装置では，光学的に遠方像をつくり，内部視標（Landolt 環）を近方へ動かした数カ所のポイントで測定を行っているため，わずか 50 cm 程度の距離で無限遠から近方までの視力測定を可能にしている．モノビジョン群では，特に中間距離で視力の両眼加算が認められたのが特徴であった．中間距離では，両眼とも defocus の状態になっているが，ほとんどの症例で全距離において良好な両眼視力が得られたのは，ボケの抑制（blur suppression）および両眼加算がうまく行われていたと考えられ，先に述べたように，眼優位性の判定を慎重に行った結果と考えた．このことから，モノビジョン法では，遠近で単に交代視を行っているのではなく，ボケの抑制および両眼加算がバランスよく行われることにより，いずれの距離においても良好な視力を得ることができると推察した．

コントラスト感度の結果では，両眼正視群では全空間周波数領域で両眼加算が認められた．これは，両眼開放下では，単眼視下のコントラスト感度に比べ約 1.4 倍の上昇（両眼加算）を示すという，これまでの報告[23,24]と矛盾しない結果であった．一方，モノビジョン群では低～中空間周波数領域のみでしか両眼加算は認められず、これまでのコンタクトレンズによる方法とほぼ一致した結果[9]であった．コントラスト感度の測定は，1.27 m の中間距離で行っており，視力測定結果（図3）からわかるように，その距離においては両眼とも defocus の状態である．刺激が defocus な場合，高空間周波数成分は失われるため，この周波数領域で両眼加算が認められなかったものと考えられる[9,25]．明室とほぼ同じ条件下で，背景とのコントラスト差が大きい Landolt 環を用いて測定している全距離視力に対し，準暗室でのコントラスト閾値の検査では刺激の性質のみならず，照度の違いにより順応レベルや瞳孔径も異なっていると考えられる．夜間運転時の対向車のヘッドライトのように暗所視で背景とのコントラスト比の高い視対象ではボケの抑制は十分に機能しないことが報告されている[6]．通常，われわれが眼にする物体は，低～中空間周波数領域の刺激が多いため，モノビジョン法でも日常生活へのコントラスト感度の影響はそれほど大きくはないと考えたが，夜間の室内など低照度で精密作業を必要とする場合には適応を慎重に行うべきである．

立体視については，加齢に伴う視力などの視機能が影響する可能性のほか[26,27]，近年では，立体の認識には注意（attention）が重要な役割を担っている可能性も示唆されている[28]．これまで，60～70 歳代半ばまでは良好な立体視が保たれていると報告されており[29~31]，国内においても，60 歳以上の高齢者を対象とした報告では，8 割以上の症例が TST による近見立体視は 100 秒以下であることが報告されている[32]．このことから，本研究の対象年齢を考えると，立体視の評価には，注意力や融像幅などの個人差のほか，一部は加齢による変化を考慮しなければならない．立体視は，Titmus circle test に代表される精密な立体視と fly test に代表される粗い立体視に大別され，両者の情報処理系は異なると推察されているが[28]，本研究では Titmus circle test を用いた．その結果，モノビジョン群の近見立体視は，近見完全矯正下よりは軽度低下していたが，中央値は 80 秒と比較的保たれていた．コンタクトレンズによるモノビジョン法でも，近見立体視は両眼視の状態から約 36 秒低下するが，平均 50～100 秒であったと報告[4]されており，本結果とほぼ一致した．従来より，立体視は視力の左右差により低下することが知られており[33]，本結果はこれに起因するものと考えられるが，日常われわれが得られる立体感は，両眼視差によるものだけではなく，陰影や運動視差などの単眼奥行き知覚によるものも含まれる．このため，本結果が高齢者の日常生活にどれほど影響があるのかは，他の両眼視機能検査法を含め，今後の課題である．

アンケートによる満足度評価では全体の 75 %で満足な結果が得られた．これまでに報告されているコンタクトレンズによるモノビジョン法での満足度は平均 76 %であり[4]，ほぼ同じ結果が得られた．本結果には，白内障手術による視力

向上への満足感や個人の生活環境も含まれるため，単純に評価することはむずかしいが，多くの症例で満足が得られたのは，眼鏡装用の煩わしさから開放されたことが最も大きな要因と考えられる．また，満足症例では，術前に屈折差がある症例の割合が高いことがわかった．今回の検討では，実際の不同視量や眼軸長の検討は行っておらず，今後の検討課題の一つである．さらに，モノビジョン法の成功には，屈折差，眼優位性，両眼視機能に加え，瞳孔径，融像，psychogenic な要素など多くの因子が関与していると示唆されており，今後，不適応症例の要因を詳細に分析することにより，眼内レンズによるモノビジョン法の成功率をさらに向上させることが重要であると考えている．

今回，筆者らが施行した眼内レンズによるモノビジョン法は，遠方から近方まで良好な視力と高い満足度が得られ，白内障術後の調節機能消失に対して有用な治療法の一つであると確信しているが，両眼視機能への影響や適応の決定については，基礎実験も含めて，さらに慎重に検討を行っていく必要がある．

本研究の一部は平成14年度文部科学省，科学研究費（基盤研究(C)(2)14571686）の補助を受けた．

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《原 著》 あたらしい眼科 21(4)：519～522，2004 ©

LASIK 術後の薄暮視の検討

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Night Vision Following Laser *In Situ* Keratomileusis

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Plano scan laser *in situ* keratomileusis (LASIK) と wavefront-guided LASIK 術後の昼間視・薄暮視の低コントラスト視力と高次収差について検討を行った．対象は，plano scan LASIK を施行した10眼と wavefront-guided LASIK を施行した11眼である．術前・術後1カ月・3カ月に CAT-2000™ (メニコン社製) を用い，昼間視・薄暮視の低コントラスト視力を測定した．収差測定は Zywave (ボシュロム社製) を用いた．Wavefront-guided LASIK は，薄暮視下の低コントラスト領域の視機能を維持できることが示唆された．

After plano scan laser *in situ* keratomileusis (LASIK) and wavefront-guided LASIK, we examined low contrast visual acuity of day and night vision, and investigated higher order aberrations. Subjects comprised 10 eyes after plano scan LASIK and 11 eyes after wavefront-guided LASIK. Using CAT-2000™, we measured low contrast visual acuity of day and night vision before and at 1 and 3 months after surgery. We suggest that wavefront-guided LASIK can maintain low contrast visual function in night vision.

〔Atarashii Ganka (Journal of the Eye) 21(4)：519～522, 2004〕

Key words：wavefront-guided LASIK，薄暮視，高次収差，低コントラスト視力，CAT-2000™．wavefront-guided LASIK, night vision, higher order aberrations, low contrast visual acuity, CAT-2000™.

はじめに

LASIK (laser *in situ* keratomileusis) が広く施行されるようになり，裸眼視力の向上のみならず術後の視機能が重要となってきている．屈折矯正手術後に比較的良い裸眼視力であっても，日常特に夜間での見えにくさを訴える場合では視力検査だけでは十分とは言いがたい．このような場合では，夜間のコントラスト感度が低下している可能性がある[1)]．LASIK 術後の夜間視機能の低下は，瞳孔径拡大による高次収差の増加が影響していると報告されている[2)]．また，LASIK 術後は術前正常者に比べて夜間視機能が低下している可能性があり，術後コマ収差の増加がみられたとされる[3)]．今回検討した wavefront-guided LASIK は，不正乱視や高次収差の治療が可能とされる術式である．そこで，収差を加味しない球面および円柱のみの plano scan LASIK と収差まで加味した wavefront-guided LASIK 術前術後の昼間視・薄暮視の低コントラスト視力[4)]を測定し，その変化と高次収差について検討を行った．

I 対象および方法

1. 対 象

対象は，神奈川歯科大学附属横浜クリニックにて plano scan LASIK を施行した中等度および高度近視症例8名10眼（男性2名，女性6名），平均年齢36.8±2.8歳（33～44歳；以下，Plano 群とする）と，同施設にて wavefront-guided LASIK を施行した中等度および高度近視症例7名11眼（男性2名，女性5名），平均年齢36.8±2.8歳（33～44歳；以下，WF 群とする）である．エキシマレーザーは Technolas 217z（ボシュロム社製）を用いた．

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2. 方　　法

各検査は，術前，術後1カ月，3カ月に測定を行った．

a. 屈折検査・視力検査

屈折測定は，RK-F1™（キヤノン社製）を用い普通瞳孔にて測定した．屈折検査後に5m遠見視力表™（TAKAGI社製）にて視力測定を行った．術後平均矯正視力/術前平均矯正視力で安全係数（safety index）を，術後平均裸眼視力/術前平均矯正視力で有効係数（efficacy index）を算出した．視力値はすべてlog MAR値とした．

b. 昼間視・薄暮視測定

CAT-2000™（メニコン社製）を用い測定を行った（図1）．比較暗室に5分間順応させた後，視力検査にて被検者の最高視力が得られた矯正レンズを用い，屈折矯正下にて測定を行った．オートモードで薄暮視，昼間視の順で片眼ずつ測定を行い，3回視標を提示し2回正答をPassとした．視力値はすべてlog MAR値で，平均値および標準偏差を算出した．検定方法は，Wilcoxon符号付順位和検定とMann-WhitneyのU検定を用い，危険率0.05以下を有意とした．

c. 収差測定

Zywave V3.21™（ボシュロム社製）を用い5 lxの暗室にて測定を行った．普通瞳孔で3回測定を行い，解析瞳孔径5.5mmとした．Zernike多項式3次から5次までを高次収差とし，各成分の3回平均値（RMS値）を収差測定値として用いた．検定方法はMann-WhitneyのU検定を用い，危険率0.05以下を有意とした．

d. 薄暮視時瞳孔径測定

測定が可能であった10眼を対象に，イリスコーダーC7364™（浜松ホトニクス社製）を装着し，比較暗室にて右眼・左眼の順でCAT-2000™の薄暮視測定を行った．1分間初期瞳孔径を測定した後，続けて薄暮視の測定を行った．初期瞳孔径を100％としたときの，薄暮視測定開始直後，薄暮視測定終了時，検査終了10秒後の瞳孔径を変化率（％）で表した．検定方法は，Wilcoxon符号付順位和検定を用い，危険率0.05以下を有意とした．

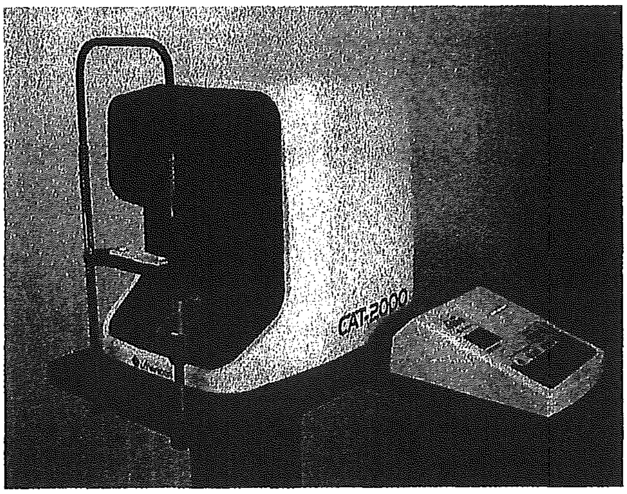

図1　CAT-2000™本体
背景輝度が一定で純粋に視標コントラストのみを変化させるので，安定した条件下での測定が可能である．

II　結　　果

1. 視　　力

Plano群は，術前矯正視力はlog MAR値で0.12±0.05（小数視力1.4），平均球面度数－5.25±1.10D（－3.5～－6.75D），平均円柱度数－0.78±0.23D（0～－1.50D），平均等価球面度数－5.56±1.16D（－4～－7.25D）であった．術後平均矯正視力はlog MAR値で0.12±0.05（小数視力1.4），平均球面度数0.03±0.03D（－0.50～0.75D），平均円柱度数－0.50±0.00D（0.00～－0.50D），平均等価球面度数0.08±0.21D，safety index 1.01，efficacy index 0.99であった．WF群では，術前矯正視力はlog MAR値で0.14±0.04（小数視力1.4），平均球面度数－6.66±1.10D（－3.5～－8.75D），平均円柱度数－1.23±0.48D（－0.25～－2.50D），平均等価球面度数－7.27±1.07D（－4.75～－9.00D）であった．術後平均矯正視力はlog MAR値で0.14±0.04（小数視力1.4），平均球面度数0.18±0.33D（－0.25～0.75D），平均円柱度数－0.88±0.40D（0.00～－1.50D），平均等価球面度数－0.24±0.26D，safety index 0.99，efficacy index 0.79であった（表1，2）．術前後のPlano群とWF群の各項目に有意差は認めなかった．

表1　術前視力および術前屈折値

	Plano群	WF群
術前裸眼視力（log MAR値）	1.33±0.02	1.43±0.03
術前矯正視力（log MAR値）	－0.12±0.05	－0.14±0.04
術前平均球面度数	－5.25±1.10D	－6.66±1.10D
術前平均円柱度数	－0.78±0.23D	－1.23±0.48D
術前平均等価球面度数	－5.56±1.16D	－7.27±1.07D

表2　術後視力および術後屈折値と各index

	Plano群	WF群
術後裸眼視力（log MAR値）	－0.12±0.04	－0.06±0.02
術後矯正視力（log MAR値）	－0.12±0.05	－0.14±0.04
術後平均球面度数	0.33±0.33D	0.18±0.14D
術後平均円柱度数	－0.50±0.00D	－0.88±0.40D
術後平均等価球面度数	0.07±0.21D	－0.24±0.26D
Safety index	1.01±0.09	1.00±0.1
Efficacy index	0.99±0.1	0.84±0.09

2．昼間視・薄暮視測定

a．昼間視力・薄暮視力

術前昼間視力は，両群間に有意差を認めなかった．Plano群は，術前術後に有意差は認めなかったが，術後視力は各コントラスト領域で，低下傾向を示した．WF群は，術前術後に有意差は認めなかったが，術後視力は各コントラスト領域で向上傾向を示した（図2）．

術前薄暮視は，両群間に有意差を認めなかった．Plano群は，術前と術後3カ月の間にコントラスト25％と10％で有意差（$p<0.05$）を認めた．WF群は，術前と術後には有意差を認めなかった（図3）．

b．Plano群とWF群の比較

昼間視，薄暮視ともに，術前と術後1カ月では両群間に有意差を認めなかった．術後3カ月でWF群はPlano群に比べ視力は良好であり，昼間視ではコントラスト25％・10％で，薄暮視ではコントラスト100％・25％・10％で有意差（$p<0.05$）を認めた（図4）．

3．高 次 収 差

Plano群とWF群との間には術前・術後1カ月に有意差を認めなかった．術後3カ月に3次収差は，WF群でPlano群に比べて有意に減少を認めた（図5）．4次・5次収差は，術前，術後1カ月，3カ月ともPlano群とWF群の間には有意差を認めなかった．

4．瞳孔変化率

初期瞳孔径は，平均6.29±0.56 mmであった．測定開始

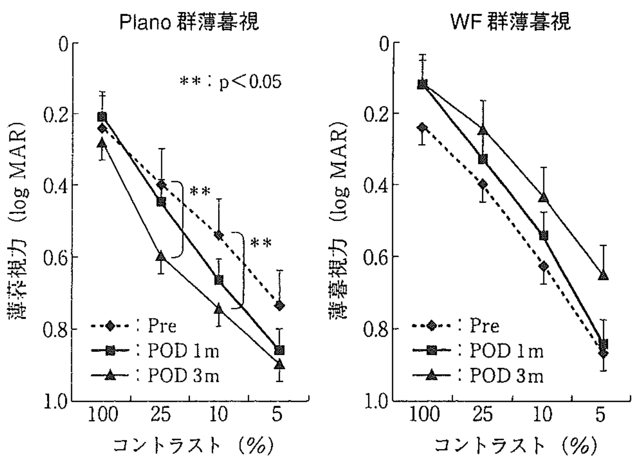

図2　Plano群とWF群の薄暮視視力変化

術後3カ月で術前に比して，コントラスト25％と10％に有意な視力低下を認めた．

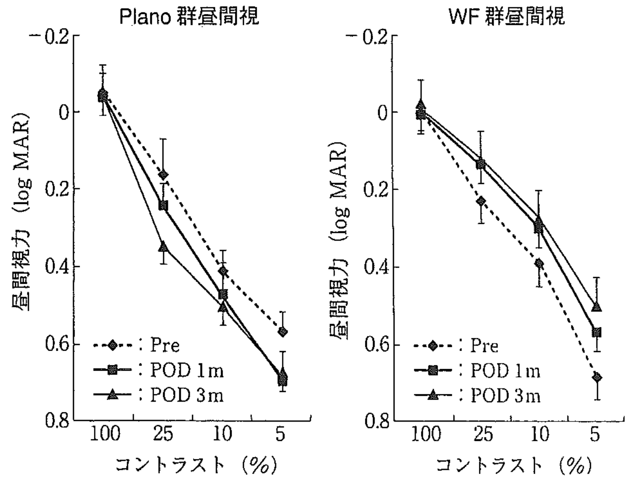

図3　Plano群とWF群の昼間視力変化

Plano群，WF群ともに各コントラスト視力には有意差は認めなかった．

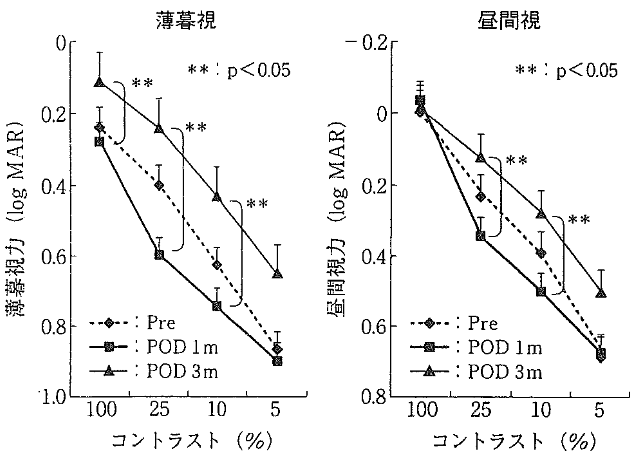

図4　Plano群とWF群との比較

薄暮視では，術後Plano群よりWF群のほうがコントラスト100・25・10％において有意に視力良好であった．昼間視では，術後Plano群よりWF群のほうがコントラスト25・10％において有意に視力良好であった．

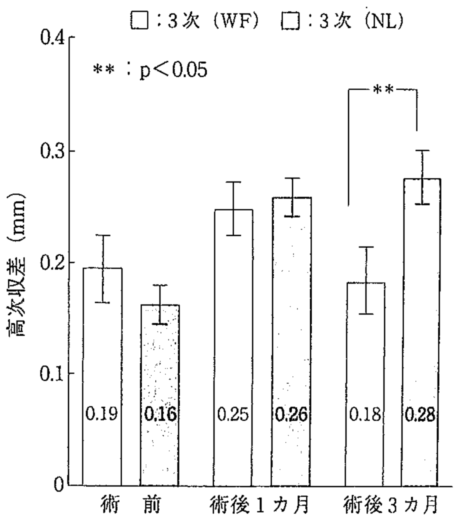

図5　3次収差の術後変化

術後3カ月でPlano群とWF群に有意差を認めた．