上の赤い線条光ははじめの60秒ほどで急激に基底と反対方向にシフトし、その後ゆっくりと基準となる眼位の方向にもどってきた。老視群の Phoria adaptation 曲線は、非老視群に比べて緩やかで、6Δ の刺激負荷では 60 秒以降 210 秒まで有意な差が認められた（t検定 $p < 0.05$ ）。12Δ に刺激負荷量を増やすと、時間的変化はさらに緩やかになり、30 秒以降 165 秒で有意差を認めた（t検定 $p < 0.05$ ）。210 秒で測定を終了し、プリズムを抜去した際に違和感を訴える被験者がいた。

2. 利得(以下 gain)

210 秒後の負荷プリズム量に対する Phoria adaptation 量の比（ gain ）は、6Δ 負荷で老視群 0.80 、非老視群 0.95 で有意差を認めた（t検定 $p < 0.05$ ）。また 12Δ 負荷では老視群 0.74 ・非老視群 0.87 であった。

3. 年齢と gain の関係

年齢と gain には弱い負の相関がみられた（ Fisher のrのz変換 $p < 0.05$ ）。20 歳から 65 歳までに、6Δ 刺激負荷で年に 1.2 %、12Δ で 1.1 %の gain の減少がみられた。

D. 考察

Schor は輻湊に関し2つの神経積分器を想定している。ひとつは高速神経積分器（ fast neural integrator ）で、輻湊刺激に対しはじめに視線を大きく修正する。次の低速神経積分器（ slow neural integrator ）は、その場に眼位を保持する役割を持つ。phoria adaptation のプリズム負荷前後の融像除去眼位（tonic vergence）の変化は slow neural integrator の活動を反映したものである。また、Phoria adaptation の機能低下はすでに眼精疲労・共同性・非共同性斜視・小脳疾患などで報告されており、今回老視によっても引き起こされることが示唆され、Phoria adaptation の加齢現象が明らかになった。

E. 結論

眼位の保持機能である Phoria adaptation は老視で低下していることが示唆された。

F．健康危険情報

なし

G．研究発表

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H．知的財産権の出願・登録状況（予定を含む）

1．特許取得　　なし
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別添４

厚生労働科学研究費補助金（長寿科学総合研究事業）
分担研究報告書

高齢者の調節刺激に対する瞳孔径・輻湊に関する研究

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研究要旨

近見反応における瞳孔変化に関する研究は、従来は単眼視による測定が主であった。しかし、日常視に近い状況での検討には両眼視による測定が望ましく、外部視標を用いた近見反応の調節、縮瞳、輻湊の三徴を他覚的に両眼同時に測定する必要があると言われていた。近年、あたらしく開発されたトライイリスは、両眼同時に調節負荷時の瞳孔反応・眼球運動が測定可能となった。このトライイリスを用いて、屈折異常以外に眼疾患のない20～50代の31名とIOL挿入眼10名の計41名で、視標を50cm（2D負荷）から14.3cm（7D負荷）まで往復させ、瞳孔径を記録した。その結果、2D負荷時には年代に応じて平均瞳孔径の減少が見られ、交感神経系機能の低下が示唆された。準静的刺激を用い近見負荷を増加させると瞳孔径は直線的に減少したが、輻湊には加齢変化がないことが判明した。

A．研究目的

トライイリスを用いて近見負荷に伴う眼球運動と瞳孔反応を測定し、加齢による変化が見られるのかどうかを検討した。

B．研究方法

対象は、屈折異常以外に眼疾患がなく、矯正視力1.0以上の20～50代の31名31眼と、IOL挿入患者（IOL群）10名10眼の計41名41眼である。内訳は、20代13眼、30代10眼、40代9眼、50代9眼、IOL群（平均69歳）10眼である。測定は、約180luxの室内照明下にて遠見完全矯正のもと、トライイリスの視標を遠点50cm（2D負荷）と近点14.3cm（7D負荷）の間を0.3D/secの速度で連続3回往復させ、その近見負荷に伴う眼球運動と瞳孔径の変化を両眼同時に記録した。初期瞳孔径は、検査説明をしながら５分間部屋の明るさに順応させ、安定したところで測定開始とした。

C．研究結果

１．瞳孔運動の加齢変化

全ての群で近見負荷増加により瞳孔径の減少、すなわち縮瞳が認められた。瞳孔径の減少は負荷に対してほぼ直線的な変化であった。更に、全ての負荷値で瞳孔径は加齢により減少した。また、2D負荷時では20代と50代間で瞳孔径に有意差が認められた。一方、7D負荷時の瞳孔径に関しても加齢とともに減少したが、各年代で有意差は認められなかった。縮瞳率に関しては、5D負荷を行って検討したが、年齢毎の有意差は見られなかった。

2．眼球運動の加齢変化

全例に近見負荷に伴う内向きの眼球運動（輻湊）が認められた。2Dから7D負荷間の移動距離（mm）には、各群間に有意差は認めなかった。

D．考察

これまで、老人性縮瞳に関しては形態学的な検討が知られていた。今回のトライイリスを用いた検討でも、近見負荷による縮瞳は加齢により減弱する傾向があることがわかった。これは、加齢に伴う交感神経系の低下と考えられる。

縮瞳率に関しては、従来の測定が内部視標による測定であったため、器械近視などの影響が微妙に介入することが多く、また、近接感の欠如がともない、両眼視差もないことから調節刺激としては不十分であると考えられていた。これに対し、今回の測定では日常視に近い状態の外部視標での測定を行えたことが大きな特徴であり、その結果、5Dの調節負荷で約30%の縮瞳を示すことが明らかになった。本装置は、こうした自然な状態に近い日常視の検討において、これからのスタンダードとなる測定方法と考えられる。

また、外部視標を用いた報告としては初めて、近見負荷によりほぼ直線的な瞳孔径の変化・眼球運動を呈することを報告することができた。

一般に輻湊は緊張性輻湊、調節性輻湊、融像性輻湊および近接性輻湊の4つから成り立っている。このうち調節性、融像性、近接性の3つは、若年者ではバランス良く保たれ、その結果調節力を十分保持していると考えられる。一方、調節力の低下した40代以降では、これらの輻湊能力が低下している可能性も考えられたが、今回の測定により、若年者と同様の縮瞳・輻湊が残存していることが示唆された。

今後、病的な瞳孔反応・調節・輻湊を評価し、高齢者に対する老視矯正支援はもちろん、IT眼症をはじめとした眼精疲労の定量評価、内眼筋異常を伴う神経疾患などの診断のためにも、トライイリスを用いた検討は臨床的に非常に有用な検査方法となることが期待される。

E．結論

外部視標を備えたトライイリスを用いることによって、より日常視に近い状態での近見反応における瞳孔反応・眼球運動の加齢変化を捉えることができた。トライイリスを用いた研究を推し進めることによって、老視のメカニズムの研究は、今後更なる発展が期待される。

F．健康危険情報

なし（?）

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H．知的財産権の出願・登録状況（予定を含む）

１．特許取得　　なし
２．実用新案登録　なし
３．その他　　なし

別添５

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書籍

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of DRP and included a study of rapid progression of DRP following endophthalmitis in contrast to two patients with unilateral chronic uveitis without DRP manifestations and severe DRP in the fellow eyes without uveitis.[3,5,6]

The rapid course of the unilateral DRP progression and the stable disease in the fellow eyes suggest that the asymmetric DRP may have occurred because of the effects of inflammatory mediators on retinal vasculature. Multiple biochemical mechanisms have been proposed to explain the pathogenesis of DRP. A major factor consists of VEGF, which is known to be a potent proangiogenic and permeability factor and has been implicated in the development of retinal neovascularizations.[7] The expression of many inflammatory cytokines is increased in the ocular fluid of patients with DRP. Likewise, high intraocular levels of VEGF were found in eyes with uveitis.[7] Because intraocular inflammation and DRP may act through similar biochemical mediators and pathways, it is possible that the elevated levels of VEGF in uveitis might have provoked the rapid development of DRP in our patients. Additionally, the vascular wall changes in the retina in posterior uveitis associated with increased leakage might have also contributed to the aggressive development of DRP. Further studies are needed to clarify our findings and hypotheses.

To conclude, our results support the hypothesis that inflammation can accelerate progression of diabetic retinopathy and point out a risk for rapid retinopathy development in eyes affected with posterior uveitis.

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Changes of Corneal Aberrations in Sitting and Supine Positions

Takushi Kawamorita, CO,
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PURPOSE: To examine the effect of posture change on corneal aberrations and corneal curvature.

DESIGN: Observational case series.

METHODS: The Keratron topographer, improved to measure patients in the supine position, was used to measure the corneal aberrations and the curvature in nine healthy volunteers. The first measurement took place with the subject in the sitting position and the others in the supine position, immediately after assuming the supine position and then 30 minutes later.

RESULTS: The total higher-order and spherical-like aberrations were significantly increased from the sitting position to the supine position ($P = .011$, and $P = .044$, Scheffé test).

CONCLUSIONS: These results suggest that the increase in the higher-order aberration from the sitting to the supine position acts to limit the improvements in visual performance after customized refractive surgery based on wavefront measurement. (Am J Ophthalmol 2006;141: 412–414. © 2006 by Elsevier Inc. All rights reserved.)

CUSTOMIZED REFRACTIVE SURGERY BASED ON WAVEfront measurement has been performed to minimize ocular higher-order aberrations.[1] However, many factors limit the ideal optical system of the human eye after customized refractive surgery.[2,3] Because the surgery is performed with the patient in the supine position, using wavefront aberration data that have been generated in the sitting position, a change in the aberration pattern because of the posture change may well be one of these factors. Thus, the purpose of this study was to perform the measurements of the corneal aberrations and the corneal curvature in both the sitting and the supine positions.

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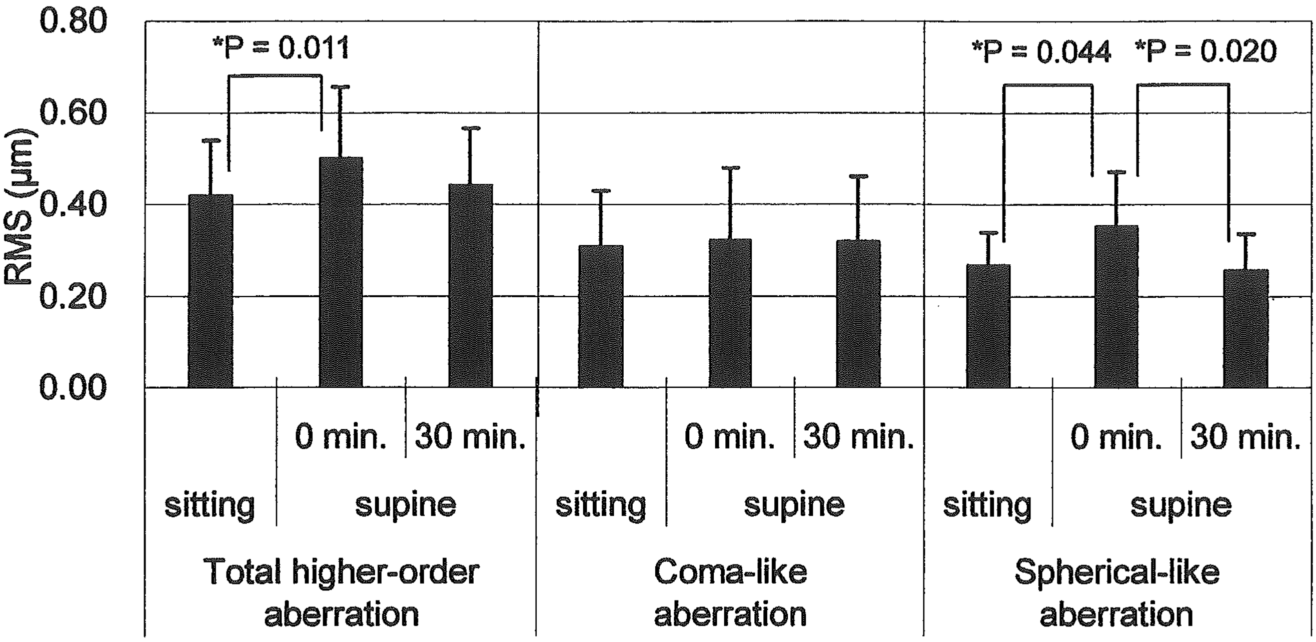

FIGURE. Comparison of corneal aberration for a 6-mm pupil diameter in sitting and supine positions (immediately and after 30 minutes). Data are expressed as mean ± standard deviation. Statistical significance: $*P < .05$; Scheffé test.

TABLE. Comparison of Corneal Curvature, Vertical Axis, Pupil Diameter, and Off-set

			Sitting	Supine 0 min.	Supine 30 min.	*P* Value
Corneal curvature (D)	3.0 mm	Steepest	43.51 ± 1.56	43.78 ± 1.74	43.74 ± 1.68	.120
		Flattest	42.12 ± 1.47	42.44 ± 1.68	42.34 ± 1.61	.148
	5.0 mm	Steepest	43.41 ± 1.57	43.79 ± 1.78	43.68 ± 1.58	.135
		Flattest	42.14 ± 1.48	42.49 ± 1.71	42.33 ± 1.58	.157
	7.0 mm	Steepest	43.27 ± 1.60	43.77 ± 1.84	43.59 ± 1.54	.124
		Flattest	41.99 ± 1.47	42.40 ± 1.71	42.22 ± 1.55	.117
Vertical axis (degrees)			93.50 ± 7.82	94.95 ± 7.80	94.29 ± 6.25	.773
Pupil diameter (mm)			3.96 ± 0.60	4.08 ± 0.54	3.82 ± 0.46	.161
Off-set (mm)			0.20 ± 0.10	0.18 ± 0.09	0.20 ± 0.08	.718

Data are expressed as mean ± standard deviation.
Statistical significance: $P > .05$; repeated measure analysis of variance (ANOVA).

Nine eyes from nine volunteers (three men, six women; aged 20 to 28 years; mean 21.9 ± 2.8 years) with no known abnormalities were included in the study. All of them were noncontact lens wearers. Informed consent was obtained from all volunteers. The tenets of the Declaration of Helsinki were followed in this study.

Corneal aberration and curvature (axial power) measurements were carried out with a Placido-ring videokeratoscope Keratron (Optikon 2000, Rome, Italy) improved to measure patients in the supine position; this topography instrument was fixed in a vertical position. Corneal wavefront aberrations were analyzed at a 6-mm pupil diameter for total higher-order, coma-like (S3 + S5), and spherical-like (S4 + S6) aberrations. Measurements were taken three times on each volunteer's left eye, and were averaged. The first measurement was taken with the subject in the sitting position and the others in the supine position, immediately after assuming the supine position and then 30 minutes later, having remained supine. The data were analyzed by repeated measure analysis of variance (ANOVA) and the Scheffé test.

The total higher-order aberration for 6-mm pupil diameter significantly increased from 0.419 ± 0.120 µm in the sitting position to 0.500 ± 0.157 µm in the supine position (Scheffé test, $P = .011$) (Figure). The spherical-like aberrations found immediately after the supine position, also showed a significant increase compared with the sitting position (Scheffé test, $P = .044$), and significantly decreased within the 30 minutes thereafter (Scheffé test, $P = .020$) (Figure). In the coma-like aberration (Figure), corneal curvature, vertical axis, pupil diameter, and off-set (Table), no significant differences were found through the experimental procedure.

Although the cyclotorsion may be associated with change in the aberration pattern,[3] we found no significant change in the vertical axis. Another factor may well have to do with the intraocular pressure. It is known that the intraocular pressure in the supine position is greater than that in the sitting position.[4] For this reason, and to avoid corneal deformation that might be caused by the measuring instrument, we did not measure intraocular pressure in this study. In vitro, Hjortdal and Jensen reported that, with the increase in the intraocular pressure, the corneal strain increased, the central corneal thickness decreased and, over time, the impact of the intraocular pressure on the corneal strain changed.[5] However, even if such changes occurred, they would only slightly affect normal eyes. Actually, there was not a considerable difference in the corneal curvature between the sitting and the supine position. This was in agreement with the result from a previous study wherein measurements were made using a handheld keratometer.[4] However, as even a slight distortion of the corneal structure can be caused by an increase in the intraocular pressure and/or the force of gravity, which of these has the greater influence is open to question. Arising from the change in posture, the aberration pattern might change during customized refractive surgery. In particular, if the cornea were to become thinner, this would result in preventing the desired improvements in visual performance.

Such factors as the effects of tear film in the supine position, or a slight tilt of the instrument, may also lead to an increase in corneal aberrations. Despite these limitations, our results suggest that the biomechanical behavior of the cornea during an operation should be considered.

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Reoperation for Persistent Myopic Foveoschisis After Primary Vitrectomy

Kaori Sayanagi, MD, Yasushi Ikuno, MD, and Yasuo Tano, MD

PURPOSE: We performed vitrectomy on two eyes for persistent myopic foveoschisis (MF) after primary surgery that did not include internal limiting membrane (ILM) peeling.

DESIGN: Interventional case reports.

METHODS: Two highly myopic eyes of two patients with persistent MF after primary vitrectomy and gas tamponade but without ILM peeling were treated with pars plana vitrectomy, residual vitreous cortex removal, ILM peeling, and long-term gas tamponade.

RESULTS: Total foveal reattachment was achieved and best-corrected visual acuity (BCVA) improved in both eyes.

CONCLUSIONS: Reoperation including complete vitreous cortex removal and ILM peeling could be beneficial for patients with persistent MF after primary surgery, indicating that vitreous cortex removal and ILM peeling are critical in treating MF. (Am J Ophthalmol 2006;141: 414–417. © 2006 by Elsevier Inc. All rights reserved.)

MYOPIC FOVEOSCHISIS (MF) TYPICALLY OCCURS IN highly myopic eyes, and optical coherence tomography (OCT) is useful for diagnosis.[1] MF is believed to occur before macular hole formation in some cases,[2] and vitrectomy and internal limiting membrane (ILM) peeling followed by gas tamponade are useful treatments.[3] However, incomplete ILM peeling may lead to persistent MF. We performed vitrectomy on two eyes (two patients) with persistent MF after primary vitrectomy. These observations imply that resolution of persistent MF and consequent visual improvement can be achieved by repeat vitrectomy with removal of residual vitreous cortex and ILM peeling.

● CASE 1: A 58-year-old woman with high myopia reported decreased vision in her right eye. She had undergone cataract surgery 7 years previously. She had visited another eye clinic and was diagnosed with posterior retinal detachment. She underwent vitrectomy and gas tamponade, and remained in a prone position for 2 weeks. Triamcinolone acetonide (TA) was not used intraopera-

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Modulation transfer function and pupil size in multifocal and monofocal intraocular lenses in vitro

Takushi Kawamorita, CO, Hiroshi Uozato, PhD

PURPOSE: To investigate the relationship between pupil size and the modulation transfer function (MTF) of a multifocal intraocular lens (IOL) in vitro and to predict the visual effects in vivo.

SETTING: Department of Ophthalmology and Visual Science, Kitasato University Graduate School of Medical Sciences, Kitasato, Japan.

METHODS: A refractive multifocal IOL (Array SA-40N, Allergan) and a monofocal IOL (PhacoFlex SI-40NB, AMO) were evaluated using the OPAL Vector system and a model eye with a variable effective aperture. With effective pupil diameters of 2.1, 3.0, 3.4, 3.9, 4.6, 5.1, and 5.5 mm, the in-focus and defocus MTFs were measured in the multifocal and monofocal IOLs.

RESULTS: With increases in effective pupil diameter, the far MTF progressively decreased at all spatial frequencies. In contrast, the near MTF began to increase at effective pupil diameter 2.1 mm, showed a peak at 3.4 mm, and decreased at diameters greater than 3.4 mm. The ratio of near MTF to far MTF showed an increase with larger effective pupil diameters and at lower spatial frequencies.

CONCLUSIONS: With a zonal progressive multifocal IOL, the pupil size effected a trade-off between the far and near MTFs: The near MTF increased at the expense of the far MTF at large pupil sizes (effective pupil diameter >3.4 mm). To enhance near vision with a multifocal IOL, the desirable effective pupil diameter should be 3.4 mm or larger.

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Multifocal intraocular lenses (IOLs) are designed to increase depth of field and to enhance near vision for cataract patients. The effectiveness of multifocal IOLs in enhancing quality of vision has been shown in many clinical studies.[1,2] The refractive design of the Array SA-40N IOL (Allergan), a typical multifocal IOL, has a beneficial effect on near vision.[3] However, many problems, including loss of corrected visual acuity at near distance and contrast sensitivity, glare, halos, and dependence on pupil size have been reported.[4–6] Pupil size affects the relative power distributions of the light generated by the zonal-progressive design of the Array IOL, whose concentric zones of progressive aspheric surfaces provide repeatable distributions of the power.[7] Furthermore, controls of optical aberration,[8] diffraction,[9] retinal illuminance,[10] pupil centration,[11] and the Stiles-Crawford effect[12] are affected by pupil size. Therefore, pupil size is expected to have an effect on the modulation transfer function (MTF), which is defined as the amplitude of the image contrast divided by the amplitude of the object contrast and is a function of spatial frequency.[13]

The aim of this study was to investigate the relationship between pupil size and near and far MTFs in a multifocal IOL in vitro. The results were used to predict the visual performance of patients with a multifocal IOL.

MATERIALS AND METHODS

The IOLs studied were the multifocal Array IOL and the monofocal PhacoFlex SI-40NB IOL (AMO). Both IOLs were 20.0 diopters (D) and 13.0 mm in length with an optic of 6.0 mm. The multifocal Array, structurally identical to the monofocal PhacoFlex according to the manufacturer's data (Table 1), is designed with 5 concentric annular refractive zones and aspheric surfaces. The additional power in the near zones, zones 2 and 4, is +3.50 D, which is approximately equivalent to +2.80 D in the spectacle plane.

The line-spread function of the multifocal and monofocal IOLs were recorded with the OPAL Vector system (Image Science Ltd.) and a model eye (Menicon Co.) composed of a wet cell

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Table 1. Optical performance in multifocal and monofocal IOLs.

	Model	
Parameter	SI-40NB	SA-40N
Refractive index	1.460	1.460
Curvature radius (mm)		
Anterior surface	10.26	10.26
Posterior surface	15.54	15.54
Central thickness (mm)	0.94	0.99
Resolution in air (c/mm)	>242	>244

(Figure 1). The MTF was calculated from the line-spread function by using fast Fourier transform techniques. The model eye consisted of a model cornea (Achromat, SSK4 and SF8), a variable effective aperture (from 2.1 to 5.5 mm), and BK7 windows. In the OPAL Vector system, the light source was confined to 546.1 nm (monochromatic e-line). The detector type used the Reticon K series silicon linear photodiode array 12.8 mm long with 512 pixels. The position of best focus was determined by measuring the variation of MTF with focus at a spatial frequency of 50 c/mm, which is approximately equivalent to 15 cycles per degree. The MTF values were formed with an average of 16 array scans.

The MTF measurements conformed to the requirements of the International Organization for Standardization, except for the effective aperture. The effective aperture sizes were sorted on the basis of (1) the optical zones in the Array IOL (2.1, 3.4, 3.9, and 4.6 mm), and (2) the 1.0 near to far area ratio, 3.0 and 5.1 mm. The effective aperture sizes were 2.1, 3.0, 3.4, 3.9, 4.6, 5.1, and 5.5 mm (Figure 2). However, in calculating the near to far area ratio, the transition zones, consisting of the aspheric surface and the intermediate zone, were disregarded.

RESULTS

The change in MTF with defocus is shown in Figure 3. The graph shows the 3-dimensional through focus response. The clinographic projections show the highest, that is, the best-focus, MTF. With the increases in effective pupil diameter, the far MTF in the vicinity of distance focus, defocus 0 D, progressively decreased at all spatial frequencies. In contrast, the near MTF in the vicinity of near focus, defocus −2.8 D, increased at effective pupil diameter 2.1 mm, showed a peak at 3.4 mm, and decreased at values greater than 3.4 mm. There was scarcely any rise in the intermediate MTF in the vicinity of intermediate focus, defocus −2.0 D, at any effective pupil diameter or spatial frequency.

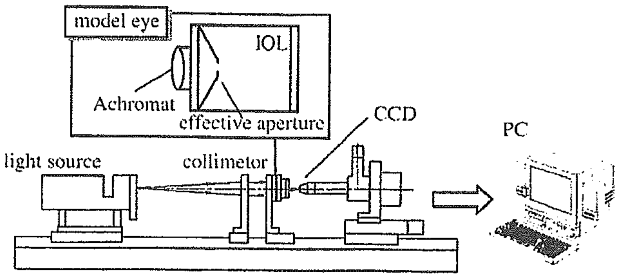

Figure 1. Structure of OPAL Vector system and a model eye with variable effective aperture.

The in-focus MTF of the multifocal and monofocal IOLs at various effective pupil diameters and 3 spatial frequencies, 100, 60, and 20 c/mm, are given in Figure 4, *A*, *B*, and *C*, respectively. The far MTF in the multifocal IOL was totally lower than that in the monofocal IOL. As the spatial frequency decreased, this difference increased. Also, although the near multifocal IOL MTF was lower than the far multifocal MTF and the monofocal MTF, the MTF of the defocus −2.8 D in the monofocal IOL showed even lower levels, approximating 0 and never more than 2% to 3%.

Figure 5 shows the far in-focus MTF normalized at effective pupil diameter 2.1 mm. With the multifocal IOL, MTF with effective pupil diameters between 2.1 mm and 3.0 mm showed the lowest rate of decline and the pace of decrease greater than 3.0 mm was approximately congruent with that in the monofocal IOL. Additionally, the attrition rate of the normalized far in-focus MTF increased slightly with increasing spatial frequencies.

Figure 6 presents the ratio of near MTF to far MTF, comparing the multifocal with the monofocal IOL. With the multifocal IOL, the ratio increased with the larger effective pupil diameters and with the decreased spatial frequencies. At high or intermediate spatial frequencies, a similar increase in the near to far MTF ratio appeared where the effective pupil diameter was greater than 3.0 mm. With the monofocal IOL, no increase in the ratio was found.

DISCUSSION

The MTF measurements in vitro have been shown to be the internationally accepted standard method for evaluating

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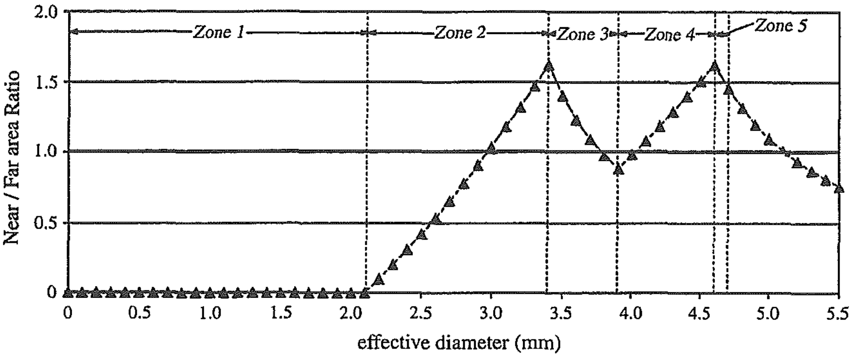


Figure 2. Near to far area ratio. The heavy line shows near to far area ratio 1.0.

the performance of IOL image quality, and it has been reported that the contrast sensitivity in vivo can be predicted from MTF values in vitro.[14] We analyzed the MTFs of multifocal and monofocal IOLs and investigated the relationship to the pupil size.

Effect of Distance Focus

The effect of defocus in any MTF depends on the effective pupil diameter and spatial frequencies, as shown in Figures 3 and 4. Based on these results, the far contrast sensitivity and visual acuity at any pupil size and spatial frequency in eyes with multifocal IOLs would be low compared with the values in eyes with monofocal IOLs. In fact, some studies have shown that distance contrast sensitivity and low contrast visual acuity with multifocal IOLs are lower than those in monofocal IOLs.[3,15] Montés-Micó et al.[16] found that distance contrast sensitivity shows deficits at higher spatial frequencies under dim mesopic conditions. However, in best corrected high contrast visual acuity, it has been reported that there is no difference.[1,3] This could be attributed to the resolution of multifocal and monofocal IOLs, which was almost the same as that shown in Table 1, or caused by aspects of the neural system.[17,18]

As illustrated in Figure 5, loss or sudden change in visual performance within the effective pupil diameter of 2.1 mm to 3.0 mm could occur, but none has been reported. Also, our finding (Figure 6) that the near to far MTF ratio at effective pupil diameters greater than 2.1 mm in multifocal IOLs increases suggests that near focus parts of lenses, particularly zone 2, have a significant impact on the far MTF.

Effect of Near Focus

From our results, it would be expected that near visual performance with a multifocal IOL is higher than that with a monofocal IOL. In clinical studies, Steinert et al.[19] report that the multifocal IOL improved uncorrected and distance-corrected near visual acuity and reduced dependency on spectacles. Montés-Micó and Alió[18] report that near contrast sensitivity improved over time but was always lower than at distance and in the monofocal near-corrected patients. The lower near contrast sensitivity was nevertheless acceptable at providing near visual function. Therefore, our results in vitro concur with their report of those in vivo.

The results shown in Figures 4 and 6 suggest that the desirable effective pupil diameter to acquire good near visual performance is a minimum of 3.0 mm, optimally 3.4 mm and larger. Because our experiment reports the actual pupil in a human eye, these data need to be converted to entrance pupil, the apparent size of the pupil, to evaluate pupil size with the multifocal Array IOL in the clinical field. The magnitude of the entrance pupil depends on corneal power, anterior chamber depth, and optical aberration, which are magnified about 13% according to Gaussian optics.[20] Therefore, the desirable pupil size would be a minimum of 3.4 mm, optimally 3.8 mm and larger. However, Hayashi et al.[6] found that a pupil diameter smaller than 4.5 mm cannot provide useful near visual acuity. Ravalico and coauthors[17] concluded that there are no differences in the relationship between visual acuity and pupil size. These differences may be ascribed to factors such as tilt or decentration of IOL[6] and corneal astigmatism,[21] which tend to decrease the MTF and reduce the sensitivity to pupil size. Also, Koch et al.[22] showed that preoperative pupil size does not predict postoperative size, and pupil size depends on age and illumination,[23] so it may be difficult for a surgeon to decide on an appropriate patient from preoperative pupil size.

Effect of Intermediate Focus

Although approximately 13% of available light in a multifocal IOL is allocated to intermediate focus, the MTFs showed low intermediate focus values at all effective pupil diameters (Figure 3). Therefore, low MTFs at intermediate focus are also supposed to lead to loss in visual performance. However, because the results were obtained in monochromatic light, they cannot be generalized to real

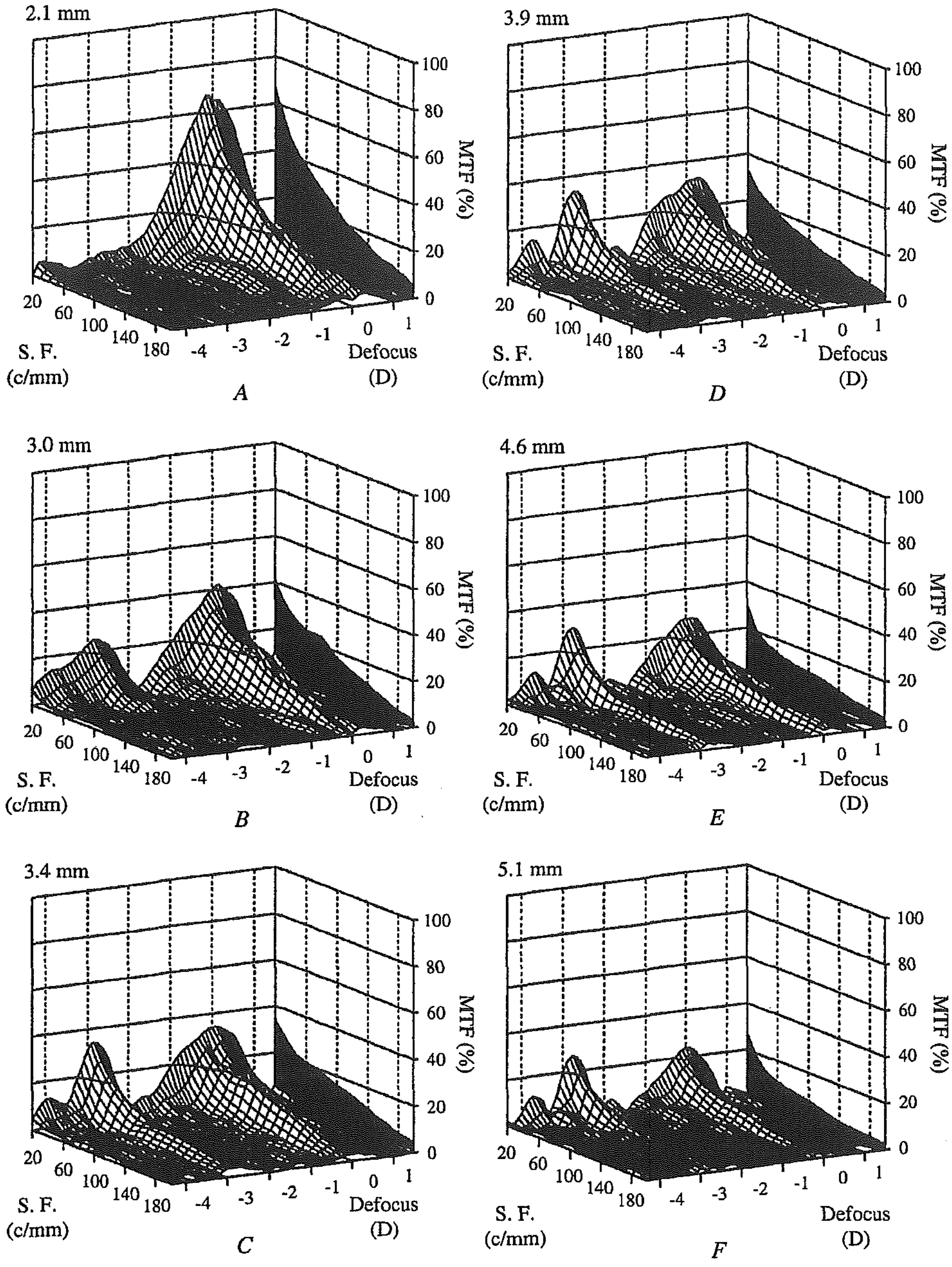
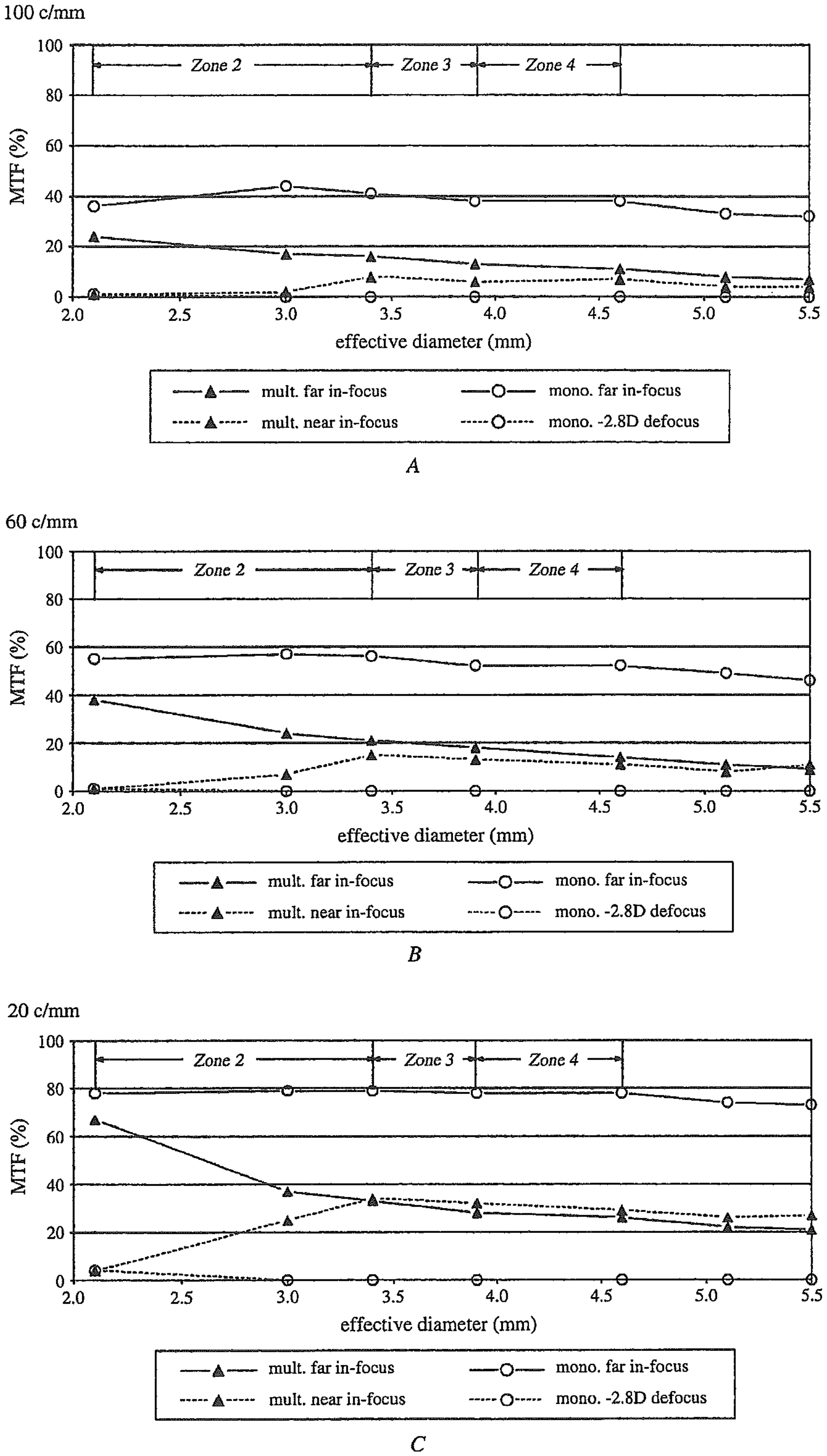


Figure 3. For various effective pupil diameters and spatial frequencies (S.F.), measured defocus MTF for the multifocal IOL.

life. In everyday white light, the longitudinal chromatic aberration will lead to an increase in the MTF at intermediate focus, which will help to improve visual performance at intermediate distances. In a clinical report, Weghaupt and coauthors[24] found that visual acuity was limited at intermediate distance. In contrast, Vaquero-Ruano et al.[25] report that Array IOLs provide excellent intermediate vision. Further studies in vitro and in vivo are needed to clarify the visual effect at intermediate distances.

Optical Performance of Multifocal IOL Array

The decrease in the MTF for multifocal IOLs is presumably caused by the inhibitory effect of in-focus and out-of-focus images produced by the far and near focus parts of lenses. Charman and coauthors[26] show there is a close correspondence between practical measurement of contrast sensitivity and the theoretical predictions of MTFs and a 50% contrast degradation of the distance



A

B

C

Figure 4. The in-focus multifocal (Mult.) and monofocal (Mono.) MTF at 100, 60, and 20 c/mm for various effective pupil diameters.

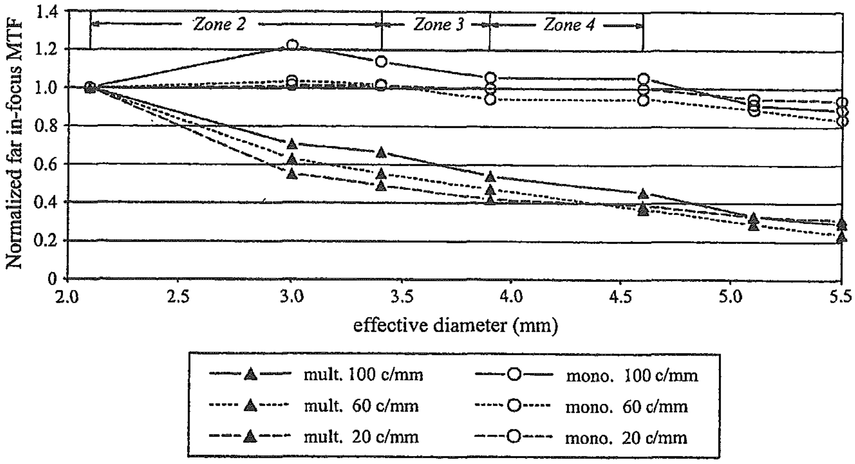


Figure 5. The far MTF normalized to the MTF at an effective pupil diameter of 2.1 mm for various spatial frequencies and effective pupil diameters. (Mult. = multifocal IOL; Mono. = monofocal IOL).

retinal image across all spatial frequencies above 3 cycles per degree, although the IOLs estimated were bifocal. Also, Holladay et al.[27] show that the multifocal IOLs had a 2-fold to 3-fold increase in depth of field with at least a 50% lower contrast in the retinal image compared with monofocal IOLs. Considering these reports and our results, the pupil size in a multifocal IOL would affect the trade-offs between (1) the depth of field and the in-focus, defocus MTF and (2) the far and near MTFs. Also, as shown in Figures 4 and 6, the distinction between zones 1 and 2 in the multifocal Array IOL depends mainly on the distribution of the trade-offs. Therefore, we have not been able to find any significance of the multiple blending zones in the multifocal Array IOL. Further in vitro and in vivo studies integrating zonal geometry are needed to determine the optimum design of the multifocal IOL.

In our laboratory measurements, each IOL was centered with respect to an effective aperture, and the phase transfer function was effectively 0. However, phase shifts greatly affect visual performance, particularly with multifocal IOLs, in terms of increased optical aberration,[28] which is caused by tilt and decentration of the IOL[6] or corneal astigmatism.[21] Also, not considered were such factors as the neural system, that is, brain adaptation,[16,17] or eye dominance.[29,30] Despite these limitations, we believe that our results are of use in predicting visual performance with multifocal IOLs, taking into consideration pupil size, far or near vision, and corrected versus uncorrected prior visual performance. In light of pupil size, further studies are needed to help identify patients for whom IOLs are indicated for whom the depth of field and near vision is enhanced.

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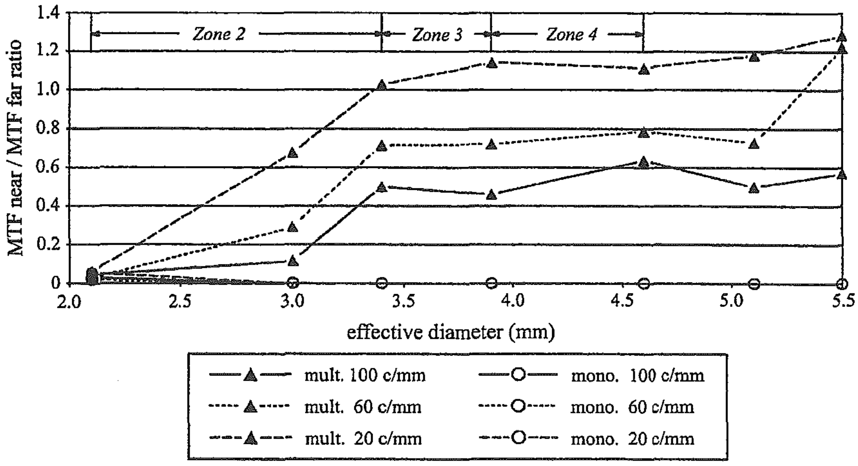

Figure 6. The ratio of near MTF to far MTF in the multifocal IOL (Multi.) compared with the monofocal IOL (Mono.).

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Posterior corneal surface changes after hyperopic laser in situ keratomileusis

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PURPOSE: To evaluate posterior corneal surface topographic changes after hyperopic laser in situ keratomileusis (H-LASIK) using Orbscan I (Orbtek, Inc.).

SETTING: Department of Ophthalmology, Nara Medical University, Nara, Japan.

METHODS: In 25 eyes of 15 patients who had H-LASIK, the posterior corneal surface was measured with slit-scanning corneal topography (Orbscan I) preoperatively and 1 year postoperatively. The center as a fit zone and calculated posterior corneal surface changes were taken at 4 points: nasal, temporal, superior, and inferior sides in the 5.0 mm diameter. The posterior corneal topographic changes were analyzed using an analysis of variance. The postoperative:preoperative magnification ratio of the posterior corneal surface was calculated in a theoretical eye model.

RESULTS: When a "+" reading was defined as the forward displacement and "−" was defined as the backward displacement, the mean posterior corneal topographic changes were −2.8 μm ± 27.9 (SD) at the nasal side, −4.5 ± 27.8 μm at the temporal side, −3.9 ± 20.1 μm at the superior side, and −2.3 ± 20.1 μm at the inferior side. The posterior corneal surface between any 2 examined points showed no significant difference after H-LASIK. In addition, the hypothetical change in the posterior cornea was −8.3 μm after +3.0 diopter H-LASIK, which was approximately closer to the study results. In each side, the amount of the attempted correction was significantly correlated with the posterior corneal topographic change.

CONCLUSIONS: Clinical measurement of the posterior corneal displacement after H-LASIK with Orbscan revealed a backward shift. This change corresponded to the hypothetical artifactual changes with Orbscan; that is, changes in the magnification ratio.

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Myopic laser in situ keratomileusis (M-LASIK) and hyperopic LASIK (H-LASIK) have been efficiently, safely, and predictably performed worldwide. However, we found several reports of keratectasia after M-LASIK,[1–3] myopic photorefractive keratectomy (PRK)[4] and posterior corneal surface changes[1,5–7] after M-LASIK. Some reports suggest that a residual corneal bed less than 250 μm or a total corneal thickness less than 400 μm could cause keratectasia.[1–4] On the other hand, to our knowledge, there are no reports of posterior corneal surface changes after H-LASIK.

With the advent of slit-scanning topography,[8] Orbscan (Orbtek Inc.), we have been able to evaluate the shape of the posterior cornea. However, the data obtained by Orbscan are limited in the accuracy of measurement. In a discussion of a study by Wang and coauthors,[1] Maloney pointed out that the accuracy of Orbscan was approximately 20 μm. Moreover, some studies report that data displayed on Orbscan may occasionally be inaccurate.[9,10] Cairns and coauthors[11] report a corneal model for slit-scanning elevation topography, but the measurement principle has not been actually described by the manufacturer.

We previously reported that the posterior corneal surface changes after M-LASIK[12] and the corneal endothelial cell changes after H-LASIK[13] may be related to the

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