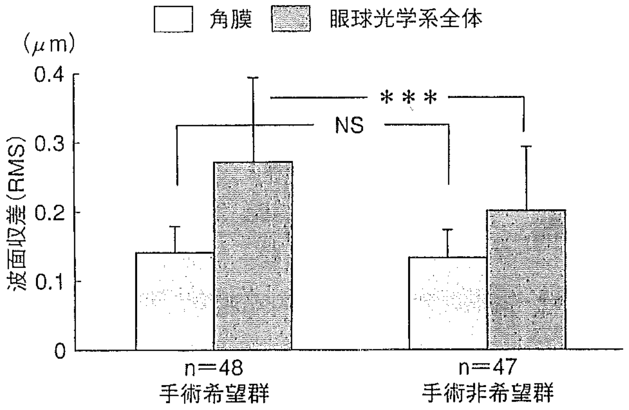

図 1 手術希望群と非希望群の高次収差(S3＋S4)の比較
Mann-Whitney の U 検定にて＊＊＊p＜0.001, NS：not significant。

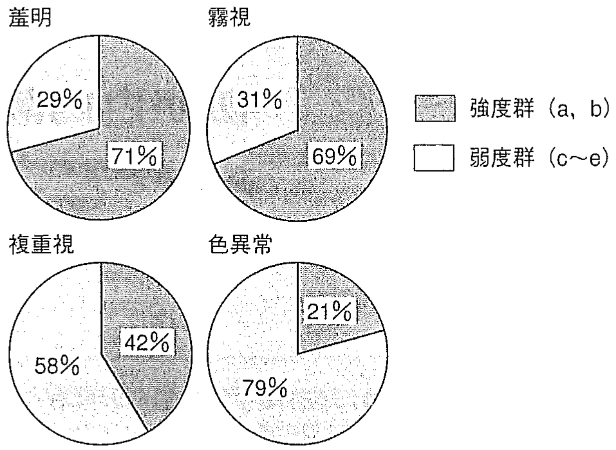

図 2 手術希望群に対するアンケートの結果

られている[10]。軽度白内障において波面収差の報告がされている[3]が，これら愁訴と高次収差の関係は報告されてない。

今回，白内障手術希望と高次収差の関係を調べるとともに，愁訴と高次収差の関係について検討したので報告する。

対象と方法

1. 対象

初期白内障と屈折異常以外に眼科的疾患がなく，収差測定時に瞳孔径 4 mm 以上確保できた 70 例 95 眼を対象とした。そのうち白内障手術希望群は 36 例 48 眼，年齢 68±9 歳（mean±SD），球面度数 0.11±3.53D，円柱度数－1.35±0.52D，矯正視力平均 1.0（0.8〜1.2）であった。手術非希望群は 34 例 47 眼，年齢 66±7 歳，球面度数－0.57±2.62D，円柱度数－1.00±0.56D，矯正視力平均 1.2（1.0〜1.2）であった。両群間の年齢，屈折度数，矯正視力に有意差はなかった（Mann-Whitney の U 検定）。

2. 方法

収差測定は Topcon 社製 KR-9000PW™を用いた。測定条件として環境照度 10 lux 以下の暗室で，1 被検眼に対し 3 回のマニュアル測定を行い，3 回の平均値を採用した。この装置は Hartmann-Shack の原理にて，Zernike 多項式により展開し，収差量を表示する。測定結果の解析には瞳孔径 4 mm での結果，total（S3＋S4）を用いた。

白内障手術希望の有無で 2 群に分け，この 2 群間における高次収差を比較検討した。さらに白内障手術希望群に対しては，愁訴に関するアンケートを行った。アンケートは羞明，霧視，複重視，色異常の 4 項目について 5 段階（a：非常に強い，b：やや強い，c：普通，d：少しある，e：ない）で評価した。5 段階のうち a，b を強度群，c〜e を弱度群とした。検定には Mann-Whitney の U 検定を用いた。

結 果

1. 手術希望群と非希望群の高次収差

白内障手術希望群と非希望群の角膜高次収差は有意差を認めなかった（p=0.42）。しかし眼球光学系全体の高次収差は手術希望群 0.272±0.122 μm，非希望群 0.201±0.092 μm と，手術希望群が有意に高かった（p＜0.001）（図 1）。

2. 手術希望群の愁訴評価と高次収差

1）羞明

手術希望群のなかで 71%（34 眼）が羞明感を訴え，他の愁訴評価に比べ最も強かった（図 2）。強度群と弱度群を比べると，角膜上の高次収差に有意差はなく（p=0.69），眼球光学系全体の高次収差において強度群が有意に高い（p＜0.001）結果となった（図 3）。

2）霧視

手術希望群のなかで 69%（33 眼）が霧視を強く訴えた（図 2）。強度群と弱度群を比べると，角膜上の高次収差に有意差はなく（p=0.42），眼球光学系全体の高次収差において強度群が有意に高い（p＜0.01）結果となった（図 4）。

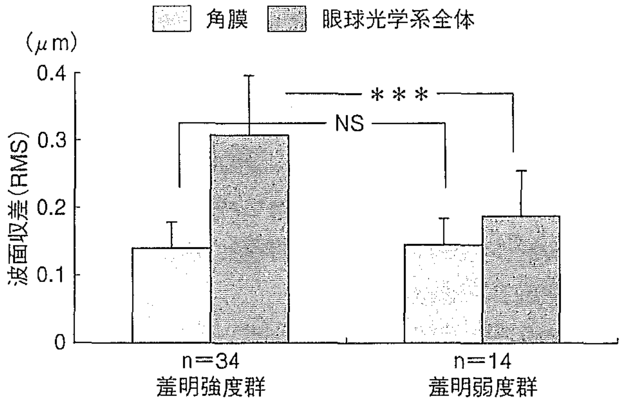

図 3　羞明における強度群・弱度群の高次収差(S3+S4)の比較

Mann-Whitney の U 検定にて＊＊＊$p<0.001$, NS：not significant。角膜高次収差は羞明強度群 0.140±0.038 μm，弱度群は 0.145±0.039 μm，眼球光学系全体の高次収差は強度群 0.307±0.089 μm，弱度群は 0.188±0.067 μm であった。

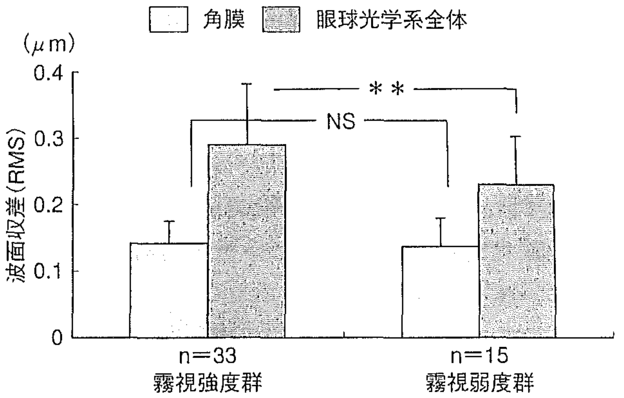

図 4　霧視における強度群・弱度群の高次収差(S3+S4)の比較

Mann-Whitney の U 検定にて＊＊$p<0.01$, NS：not significant。角膜高次収差は霧視強度群 0.141±0.034 μm，弱度群は 0.136±0.043 μm，眼球光学系全体の高次収差は強度群 0.290±0.092 μm，弱度群は 0.230±0.073 μm であった。

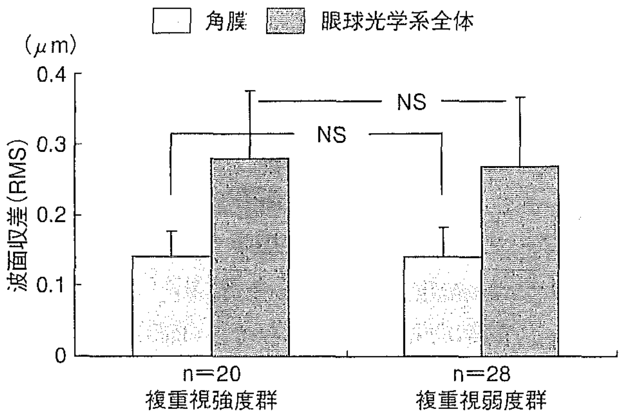

図 5　複重視における強度群・弱度群の高次収差（S3+S4）の比較

Mann-Whitney の U 検定にて, NS：not significant。角膜高次収差は複重視強度群 0.141±0.036 μm，弱度群は 0.142±0.040 μm，眼球光学系全体の高次収差は強度群 0.279±0.097 μm，弱度群は 0.267±0.099 μm であった。

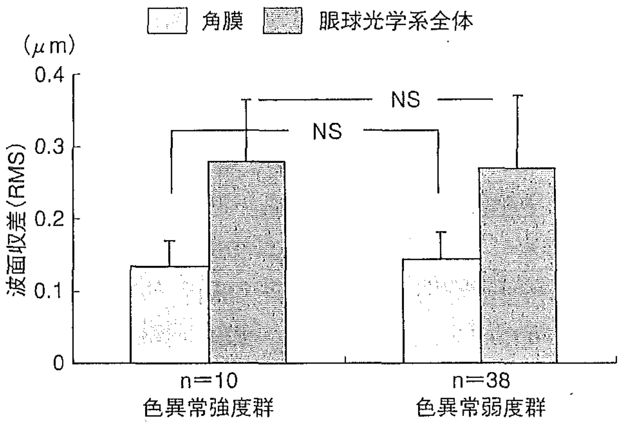

図 6　色異常における強度群・弱度群の高次収差（S3+S4）の比較

Mann-Whitney の U 検定にて, NS：not significant。角膜高次収差は複重視強度群 0.134±0.037 μm，弱度群は 0.143±0.038 μm，眼球光学系全体の高次収差は強度群 0.278±0.086 μm，弱度群は 0.270±0.101 μm であった。

3）複重視

手術希望群のなかで 42%（20 眼）が複重視を強く訴えた(図 2)。強度群と弱度群を比べても，角膜（p=0.96），眼球光学系全体（p=0.45）ともに高次収差に有意差はなかった。また強度群 20 眼の平均円柱度数は－1.31±0.40D，弱度群 28 眼では－1.37±0.59D であり，有意差（p=0.87）を認めなかった（図 5）。

4）色異常

手術希望群のなかで 21%（10 眼）が色異常を強く訴えた(図 2)。強度群と弱度群を比べても，角膜（p=0.64），眼球光学系全体（p=0.53）ともに高次収差に有意差はなかった（図 6）。

考按

白内障患者における「見えにくさ」は従来，主に視力検査で評価されてきた。しかし実際の臨床においては，視力値が良好であるにもかかわらず，不定愁訴的な視覚の不満や手術希望を訴える症例に遭遇する。白内障患者における視覚障害の程度は多岐にわたり，またその生活背景の諸要因から，患者本人の手術に対する要求もさまざまである。手術技術の向上，情報の広まりにより患者が術後に求める理想は高くなる一方である。そのため術

前に患者の視覚障害に対する不満の所在とその程度を把握することが必要になってきている。視力に頼る評価ではなく，実生活における視覚の新しい評価法が検討されてきている。コンラスト感度での評価，また Barnth-Petersen 法[7]や VF-14[8]，金沢医大式問診[9]などのアンケート評価が報告されている。

Barnth-Petersen 法では読書能力，遠方視力，テレビなどの中間距離視力，家事など日常の視力の 4 点をスコア化したが，点数設定の根拠が曖昧な点が指摘されている[7]。VF-14 では質問項目が多く日常生活に関して具体的で，中近距離も重視されており，7 割が細かい字の見にくさ，2 割がテレビの見にくさを強く訴えた[8]。金沢医大式の問診では，視力 0.7 以上の良好群において，まぶしさに対する訴えが多く，また極端に視力が低下している者より比較的視力が良好な者ほど訴えが多い傾向がみられたと報告している[9]。しかしこれらのアンケートはすべて簡便であるが，自覚的・主観的な評価といえる。それに対し他覚的な方法として，画像解析により水晶体の変化をとらえる前眼部解析装置（EAS-1000）を用いた方法などが報告されている[12]が，解析，評価法といった点での簡便さに欠けていると思われる。

同じ矯正視力であっても，患者の訴える「見えにくさ」にはかなりの幅がある。今回のアンケート調査においても，同じ矯正視力でありながら訴えの程度や種類がまったく異なるものが多くみられた。今回，アンケートを行った 4 項目（羞明，霧視，複重視，色異常）は過去に報告されたアンケート評価法の項目も加味しつつ，実際に臨床において訴えの多いものから選択した。

今回の検討では手術希望群において，羞明感を訴える患者の割合が一番多かった。この羞明は「視野内の余計な光による物の見え方が悪くなる現象」であり，眼内での光の散乱によって生じると考えられる。以前から羞明，霧視感といった見えにくさは主として混濁による散乱が原因とされてきた。散乱と年齢の間には相関があり，また年齢とともに高次収差は増加するが，散乱と高次収差には相関がみられなかったとの報告がある[13]。今回の手術希望群は視力が良好であり，散乱が視力低下を及ぼす前段階であると考えられる。今回，初期白内障の愁訴のなかでも特に羞明感や霧視感は高次収差量に伴い増加した。散乱強度としてではなく，羞明感，霧視感といった愁訴を高次収差によって他覚的・数値的に評価することができる可能性が示唆された。しかし今後さらに初期白内障における愁訴と散乱の関連に関して，検討の余地があると思われた。

複重視や色異常といった訴えは，今回過半数以下にとどまった。単眼での複重視は水晶体の不規則な屈折が主な原因と考えられるが，今回手術希望の有無と円柱度数に有意差はなく，また高次収差においても関連性が得られなかった。

一般的に診断や治療方針決定のために必要な検査は，短時間に，患者に苦痛なく，正確に行うことが最も重要であるとされている。波面センサーでの検査は検査時間も短く，患者への負担も少なく，客観的かつ定量的に評価できる点で適しているといえる。高次収差測定により，簡便かつ客観的に初期白内障を評価することが可能であると考えられた。今後，視機能を評価するツールとして波面センサーがますます活用され，見え方の質，すなわち quality of vision を定量化する手段の 1 つとして高次収差が用いられる可能性が示唆された。

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遠視 LASIK における高次収差変化

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High-Order Optical Aberration Changes after Hyperopic Laser *In Situ* Keratomileusis

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遠視 LASIK (laser *in situ* keratomileusis) 術後1年が経過した患者に対し，矯正量と高次収差の関係について検討を行った．方法は，ニデック社製エキシマレーザー EC-5000 を使用し，オプチカルゾーン直径 5.5 mm，トラディションゾーン直径 8.0 mm で遠視 LASIK を行った．対象は術後1年経過した9例16眼で，平均年齢は 58.6±13.0歳（37～78歳）であった．矯正量は，平均＋3.25 D±1.18 D（範囲：2～6 D）であった．高次収差測定には，トプコン社製 KR-9000PW™ を使用し，角膜ならびに全眼球における直径 4.0 mm 領域の（S3）・（S4），直径 6.0 mm 領域の（S3＋S5）・（S4＋S6），それぞれの root mean square (RMS) を求め解析を行った．遠視 LASIK 術後1年において，矯正量が大きくなるにつれ高次収差が増加する結果が示された．それぞれの相関係数は，4.0 mm 領域では（S3）：角膜 r＝0.269，全眼球 r＝0.553，（S4）：角膜 r＝0.540，全眼球 r＝0.537 で，一方，6.0 mm 領域では（S3＋S5）角膜 r＝0.225，全眼球 r＝0.696，（S4＋S6）角膜 r＝0.488，全眼球 r＝0.571 であった．今回，角膜のコマ様収差（S3）・（S3＋S5）を除き，全眼球のコマ様収差ならびに角膜・全眼球の球面様収差は，矯正量に伴い有意に増加する結果が示された．

Purpose：To evaluate the relation between the amount of correction and the amount of high-order optical aberrations in eyes that underwent hyperopic LASIK (laser *in situ* keratomileusis). Methods：High-order aberrations were measured using the TOPCON KR-9000PW™ in 16 eyes of 9 patients that had undergone hyperopic LASIK 1 year previously. The patients mean age was 58.6 years (range：37～78 yrs). Mean attempted correction was 3.25 D (range：2～6 D). The NIDEK EC-5000 excimer laser was used with optical zones of 5.5 mm and transition zone of 8.0 mm. We used the root mean square (RMS) of (S3)・(S4) in the 4.0 mm and (S3＋S5)・(S4＋S6) in the 6.0 mm central zone to analyze corneal and total ocular aberrations. Correlation coefficients between each RMS and the attempted correction were statistically analyzed. Results：The amount of high-order optical aberrations correlated with the amount of attempted correction at one year after hyperopic LASIK. Correlation coefficients in the 4.0 mm central zone were 0.269 (S3) and 0.540 (S4) for corneal aberrations, 0.553 (S3) and 0.537 (S4) for total ocular aberrations. Correlation coefficients in the 6.0 mm central zone were 0.225 (S3＋S5) and 0.488 (S4＋S6) for corneal aberrations, 0.696 (S3＋S5), and 0.571 (S4＋S6) for total ocular aberrations. Conclusion：The result of this study suggests that the amount of coma-like aberrations of the eye and the amount of spherical-like aberrations of the cornea and the eye significantly correlate with the amount of attempted correction. However, the amount of coma-like aberrations of the cornea (S3)・(S3＋S5) did not correlate with the amount of attempted correction.

〔Atarashii Ganka (Journal of the Eye) 21(9)：1237～1240, 2004〕

Key words：屈折矯正手術，遠視 LASIK，高次収差，視機能．refractive surgery, hyperopic LASIK, high-order optical aberrations, optical quality.

はじめに

近年，手術手技の確立より LASIK (laser *in situ* ketatomileusis) は，術後屈折値の安定が早く，疼痛の少ない点などから主として行われるようになってきた．*LASIK* を含む屈折矯正手術後の視機能の評価法としては，2次収差である，球面レンズ・円柱レンズ値やコントラスト感度値でおもに評

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価されている．しかし，屈折矯正手術後に，自覚的な視機能障害を訴える患者に対しての評価は困難であった．近年，波面センサーが開発され，高次波面収差の測定により不正乱視の評価や数値化が可能となった[1～3)]．

PRK（photorefractive keratectomy）やLASIKにおける近視矯正では，エキシマレーザーを中央部に照射するのに対し，遠視矯正では，周辺部にドーナツ状に照射を行うことで中心部をスティープ化させる．遠視矯正手術後の角膜は[4)]，角膜上にフラットの形状とスティープの形状が混在し，近視矯正と比較してより非球面形状を示す．

角膜屈折矯正手術において，良好な矯正効果を得るためにセンタリングは，重要な要素となり[5)]，センタリングのズレは，球面収差やコマ収差の発生の原因となる[6)]．また，高次収差の増加は，コントラスト感度や視機能に影響することが知られている[7,8)]．しかし，角膜屈折矯正手術後の角膜における高次収差の変化については報告されている[9～11)]が，全眼球の高次収差がどのように影響するかはまだよく知られていない．

筆者らは，遠視LASIK後1年経過観察が可能であった症例に対し，高次収差を測定し矯正量との関係について検討を行った．

I 対象および方法

遠視LASIKの臨床治験（治験統括医：増田寛次郎）を施行し，術後1年以上の経過観察が可能であった9例16眼を対象とした．年齢は37～78歳（平均58.6±13.0歳）．術前の自覚的屈折度数は，等価球面値で＋3.25±2.75D（0.75～10.1D）であった（表1）．患者の選択にあたり，術前に視力検査・屈折検査・眼圧検査・Schirmerテスト・角膜内皮検査・角膜形状解析・コントラスト感度検査・前眼部および眼底検査を行い，矯正視力1.0以上，その他眼疾患を認めない患者に対して手術を行った．

表1 遠視LASIKの背景

症例数	9例16眼
年齢（歳）	58.6 ± 13.0
矯正量（D）	3.25 ± 1.18（2～6D）
自覚的屈折度数	
等価球面値（D）	
術前	＋3.27 ± 2.75
術後	＋1.50 ± 1.67

（平均± SD）

エキシマレーザーは，ニデック社製EC-5000を全症例に使用した[12)]．レーザーの仕様は，波長193 nm，発振周波数30 Hz，切除率0.6 μm/スキャン，オプチカルゾーン直径5.5 mm，トラディションゾーン直径8.0 mm．マイクロケラトームは，ニデック社製MK-2000を使用し，フラップ厚160 μm，フラップ径9.5 mmの設定で行った．

矯正量は，平均＋3.25D±1.18（2～6D）であった．1例のみ乱視矯正を同時に行ったが，他の全例は球面のみの矯正を行った．1例の円柱矯正度数は0.75Dであった．

高次収差の測定には，Hartmann-Shack波面センサー（KR-9000PW™，トプコン社製）を用いた．解析方法はZernike多項式で展開された3次，4次，5次および6次収差のroot mean square（RMS）を求め，Photopic Visionの4.0 mm領域では3次のコマ様収差（S3）と4次の球面様収差（S4）を，Scotopic Visionの6.0 mm領域では3次と5次のコマ様収差（S3＋S5）ならびに4次と6次の球面様収差（S4＋S6）を計算し，おのおのの求められた収差量と矯正量の関係を角膜ならびに全眼球ついて検討を行った．なお，今回術前の高次収差は，術前に波面収差測定ができなかったため，術前にEyeSys™で測定した角膜形状をもとに高次収差解析ソフトVOL-CT（Sarver and Associates, Inc, Florida USA）を使用し計算を行った．

II 結果

術前の角膜の高次収差は表2に示す．遠視LASIK手術においてepithelial ingrowth（1例），術中出血（3例），術後1年での鉄染色（6例）を認めた以外に術中術後でのfree flap，button hole，thin flap，フラップのズレなどの合併症は認められなかった．

1. Photopic Visionにおける術後の収差

4.0 mm領域における高次収差の結果は，角膜による3次のコマ様収差（S3）：0.139±0.073 μm（means±SD），4次の球面様収差（S4）：0.062±0.044 μmであった．全眼球に

表2 遠視LASIKにおける角膜・眼球の高次収差RMS（μm）の変化（平均± SD）

		4.0 mm zone 術前	4.0 mm zone 術後		6.0 mm zone 術前	6.0 mm zone 術後
角膜	(S3)	0.085 ± 0.038	0.139 ± 0.073	(S3 ＋ S5)	0.266 ± 0.146	0.503 ± 0.286
	(S4)	0.050 ± 0.021	0.062 ± 0.044	(S4 ＋ S6)	0.244 ± 0.085	0.407 ± 0.300
全眼球	(S3)	—	0.237 ± 0.151	(S3 ＋ S5)	—	0.754 ± 0.489
	(S4)	—	0.100 ± 0.058	(S4 ＋ S6)	—	0.551 ± 0.489

術前の高次収差は，EyeSys™のAxalMAPから高次収差解析ソフトVOL-CTを使用し計算．

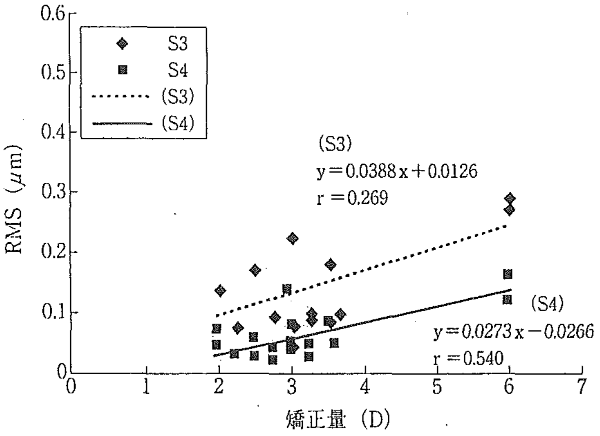

図1 4.0 mm 領域の角膜における遠視矯正量に伴う高次収差の変化

遠視の矯正量の増加に伴い角膜における4次の球面様収差(S4)が増加を示す($p<0.05$).

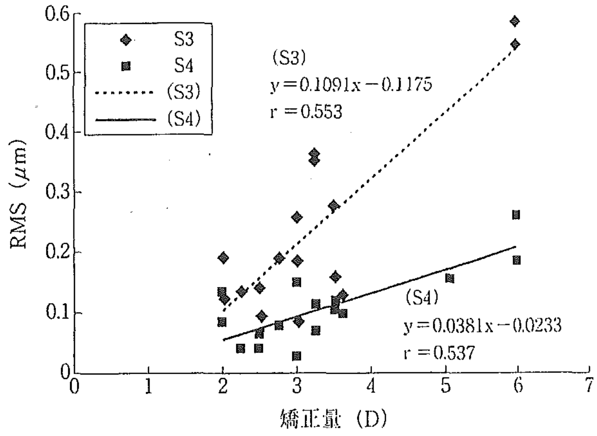

図2 4.0 mm 領域の全眼球における遠視矯正量に伴う高次収差の変化

遠視の矯正量の増加に伴い全眼球における3次のコマ様収差(S3)と4次の球面様収差(S4)が増加を示す($p<0.02$).

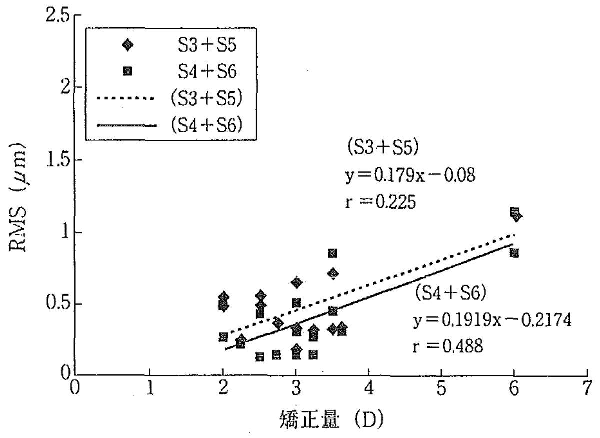

図3 6.0 mm 領域の角膜における遠視矯正量に伴う高次収差の変化

遠視の矯正量の増加に伴い角膜における4次と6次の球面様収差(S4+S6)が増加を示す($p<0.05$).

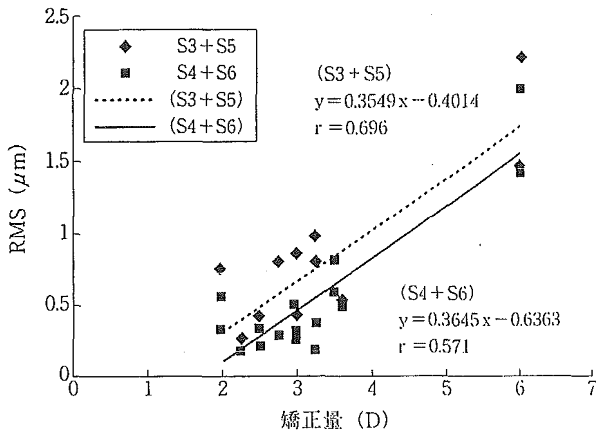

図4 6.0 mm 領域の全眼球における遠視矯正量に伴う高次収差の変化

遠視の矯正量の増加に伴い全眼球における3次と5次のコマ様収差(S3+S5)と4次と6次の球面様収差(S4+S6)が増加を示す($p<0.02$).

よる収差(S3)は平均0.237±0.151 μm, (S4)は0.100±0.058 μm であった. 角膜による収差と矯正量との相関関係は, (S3)と矯正量の間に有意な相関が認められなかったが, (S4)と矯正量の間に有意な相関が認められた(図1). 全眼球による収差と矯正量との相関関係は, (S3)・(S4)ともに矯正量との間に有意な相関が認められた(図2).

2. Scotopic Vision における術後の収差

6.0 mm 領域における高次収差の結果は, 角膜による3次と5次のコマ様収差(S3+S5):0.503±0.286 μm (means±SD), 4次と6次の球面様収差(S4+S6):0.407±0.300 μm, 全眼球による収差(S3+S5):0.754±0.489 μm, (S4+S6):0.551±0.489 μm であった. 角膜による収差と矯正量との相関関係は, (S3+S5)と矯正量との間に有意な相関が認められなかったが, (S4+S6)と矯正量との間に有意な相関が認められた(図3). 全眼球による収差と矯正量との相関関係は, (S3+S5)・(S4+S6)ともに矯正量との間に有意な相関が認められた(図4).

III 考　　按

屈折矯正手術はその手技の確立により, PRK に代り LASIK が主として行われるようになってきた. 術後の裸眼視力向上は重要であるが, 加えて術後の QOV (quality of vision) を考えるうえで, 眼鏡や CL (コンタクトレンズ) で矯正できない高次収差の影響について議論されるようになってきた. Oshika ら[9]は, 術前等価球面値−2.25〜−5.50 D に行った近視 LASIK において, 瞳孔径3.0 mm と7.0 mm での球面様収差(S4+S6)およびコマ様収差(S3+S5)について検討

を行い，術後角膜における高次収差の増加を報告している．また，Wangら[10]は，遠視LASIKにおいて，術前と術後3カ月間における3次から6次までの高次収差について角膜の3.0 mmと6.0 mm領域おける矯正量に伴う高次収差の平均値の変化について，Visx Star S2：3.0 mm領域で術前0.099 μm，術後0.143 μm，6.0 mm領域で術前0.485 μm，術後0.557 μm，Visx Star S3：3.0 mm領域で術前0.108 μm，術後0.105 μm，6.0 mm領域で術前0.493 μm，術後0.560 μmと報告し，コマ収差においても同様に術後増加する結果を報告している．これまで多くの報告において，角膜前面形状から得られる高次収差について検討を行っているが，遠視LASIK後の角膜ならびに角膜を含む眼球全体の収差についての検討はあまりなされていない．今回の結果から，角膜における球面様収差，全眼球におけるコマ・球面収差において，矯正量の増加に伴い収差が増加する結果が示されたが，しかし，角膜のコマ様収差である4.0 mm領域の（S3），6.0 mm領域の（S3＋S5）において，矯正量と高次収差の間に統計上の有意な相関が認められなかった．この理由として，コマ収差の生じさせるセンタリングのズレは，術後角膜トポグラフィーから求められた値では，平均0.68±0.44 mmであり，Mrochenら[6]は，センタリングのズレの量に伴い角膜でのコマ様収差が増加すると報告しているが，今回の結果では矯正量とセンタリングのズレの相関性は認められなかった．また，矯正量とコマ様収差の相関において，角膜と全眼球の両者間に異なる結果が生じた理由として，眼球の高次収差は，角膜の収差とその他の収差で眼球全体のバランスを保っており[13]，特にコマ収差の補正関係が影響するのではないかと考えられる．

今回遠視LASIKを行い，術後1年経過し角膜形状が安定した患者に対して高次収差の測定を行った．結果の検討における問題点は，術前と術後で高次収差の測定が異なる器械を使用している点にある．しかし，矯正量と高次収差の間に正の相関が認められた結果から術前の高次収差の測定は，他の器械で代用して問題は少ないと考えられる．また，対象年齢が平均58.6歳であり，眼球全体の高次収差を検討するうえで，白内障を伴う屈折値や高次収差の変化[14]が問題となる．最高年齢が78歳で白内障による影響を考慮する必要があるが，術前の矯正視力は1.0であり，術前のスリット所見より，白内障による影響はきわめて少ないと判断し，治験症例に加えた．術後の矯正視力も1.0であり，変化は認めなかった．また，術後の高次収差の結果と他の症例との比較検討を行ったが，白内障の影響は少ないと推測された．

全眼球の収差のバランスが変化する角膜屈折矯正手術において，QOVを考える際，全眼球における収差の検討がより重要である．正常角膜に行う角膜屈折矯正手術は，裸眼視力の向上をもたらすが，その反面少なからず高次収差の増加をもたらす．高次収差に関する研究ははじまったばかりであるが，高次収差の増加がどの程度あれば許容されるかは今後検討していく必要があると思われる．

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⑦

Ocular dominance and patient satisfaction after monovision induced by intraocular lens implantation

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Purpose: To elucidate the relationship between ocular dominance and patient satisfaction with monovision induced by intraocular lens implantation.

Setting: Eye Clinic, Kitasato University School of Medicine Hospital, Sagamihara, Kanagawa, Japan.

Methods: The durations of exclusive visibility of dominant- and nondominant-eye targets were measured in 16 patients with successful monovision and 4 patients with unsuccessful monovision to determine the characteristics of ocular dominance. The dominant eye was determined using the hole-in-card test (sighting dominance). The contrast of target in nondominant eye was fixed at 100%; the contrast of target in the dominant eye varied (ie, 100% to 80% to 60% to 40% to 20%) using rectangular gratings of 2 cycles per degree that were 4 degrees in size.

Results: In the successful monovision group, the reversal thresholds (ie, exclusive visibility of the nondominant eye crosses over that of the dominant eye) were displayed only at low decreasing contrast (80% and 60%). However, in the unsuccessful monovision group, the reversal thresholds were at high decreasing contrast (20%) or not at all. The reversal thresholds in patients with unsuccessful monovision were at a significantly lower contrast than in patients with successful monovision ($P<.05$).

Conclusions: Success and patient satisfaction in monovision patients were significantly influenced by the magnitude of ocular dominance. The balance technique seems to be a good method to evaluate the quantity of ocular dominance and prospectively evaluate the monovision technique.

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Monovision is a means of presbyopic correction in which 1 eye is corrected for distance vision and the other eye for near vision.[1] In clinical practice, the dominant eye is commonly corrected for distance.[1] This practice is based on the assumption that it is easier to suppress blur in the nondominant eye than in the dominant eye. This has not been quantitatively investigated with regard to several factors such as the degree of ocular dominance. Most clinicians are unable to evaluate whether a patient will be able to adjust to monovision correction. Therefore, monovision limitations in refractive surgery have not been clearly defined in the current ophthalmic literature, although the monovision success rate with contact lens correction is high.[1,2]

Ideally, the patient with monovision should be able to see clearly at all distances. The binocular clear-vision range should be continuous and equal to the sum of the monocular clear ranges without interference from blurred images in 1 eye. However, input from the dominant eye produces a greater response to a given stimulus

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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.

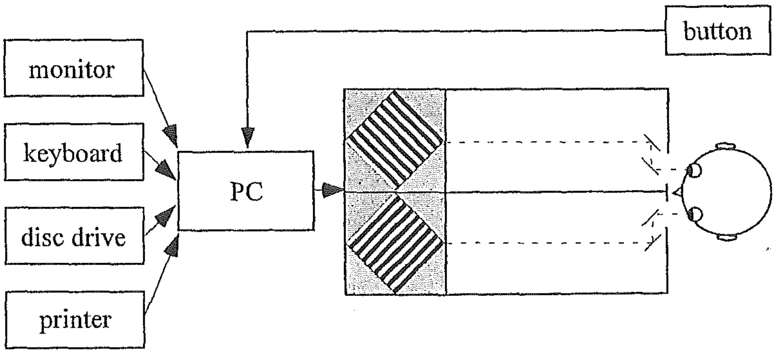

Figure 1. (Handa) Computer screen setup to test binocular rivalry.

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

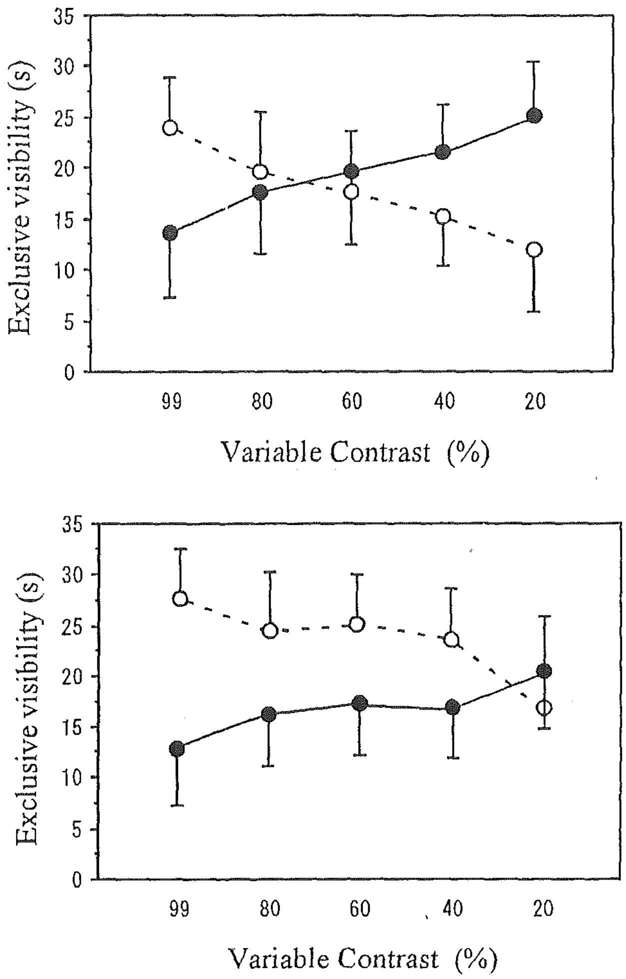

Figure 2. (Handa) Exclusive visibility by contrast level. *Top*: Exclusive visibility in the dominant eye in the successful monovision group. *Bottom*: Exclusive visibility in the dominant eye in the unsuccessful monovision group. The open circles and the dashed line represent exclusive visibility in 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.

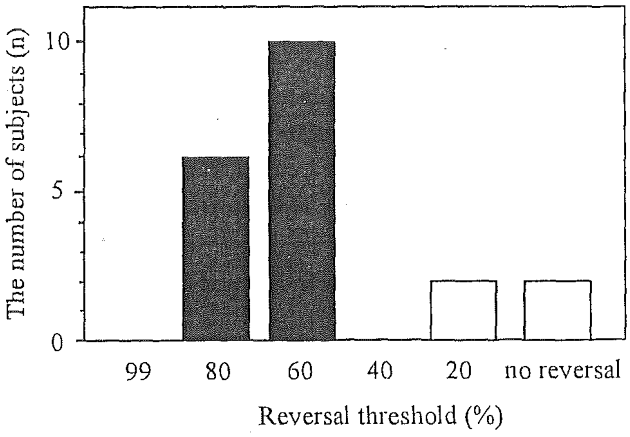

Figure 3. (Handa) Reversal thresholds. The black bars represent reversal thresholds in the successful monovision group and the white bars, the thresholds in the unsuccessful monovision group.

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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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

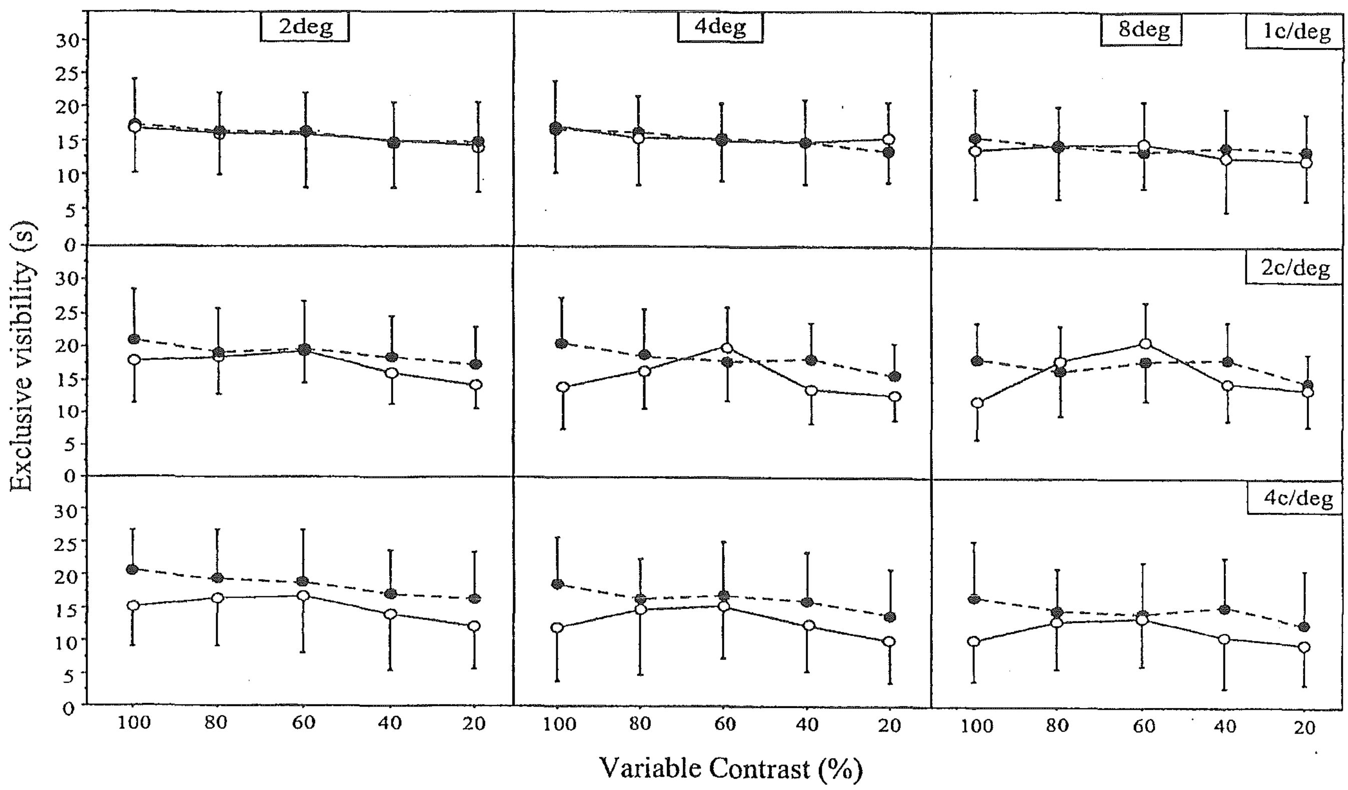

FIGURE 1.
The total duration of exclusive visibility with decreasing contrast are shown for three spatial frequencies (1, 2, and 4 cpd) and three target sizes (2, 4, and 8°). Solid circles and dashed lines represent the total duration of exclusive visibility of the dominant eye target, and open circles 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).

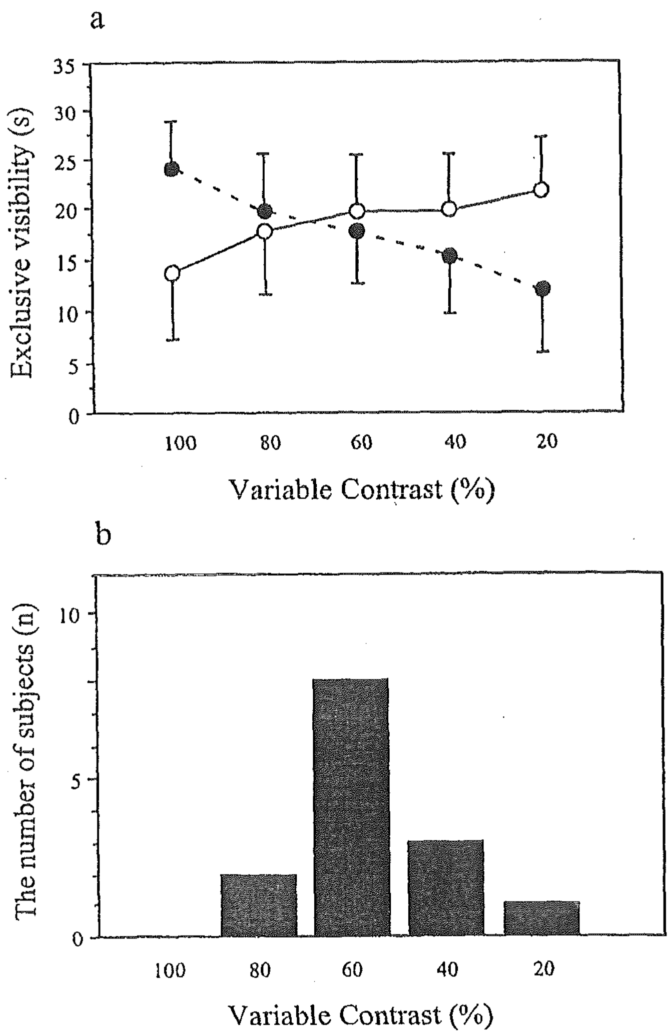

FIGURE 2.
A: The total duration of exclusive visibility seen with decreasing contrast in the dominant eye is shown for the 2 cpd at 4°. Solid circles and dashed lines represent the total duration of exclusive visibility of the dominant eye target, and open circles and solid lines represent the total 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.

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