Mechanism of Action of the Tetraflex Accommodative Intraocular Lens

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ABSTRACT

PURPOSE: To investigate the mechanism of action of the Tetraflex (Lenstec Kellen KH-3500) accommodative intraocular lens (IOL).

METHODS: Thirteen eyes of eight patients implanted with the Tetraflex accommodating IOL for at least 2 years underwent assessment of their objective amplitude-of-accommodation by autorefraction, anterior chamber depth and pupil size with optical coherence tomography, and IOL flexure with aberrometry, each viewing a target at 0.0 to 4.00 diopters of accommodative demand.

RESULTS: Pupil size decreased by 0.62±0.41 mm on increasing accommodative demand, but the Tetraflex IOL was relatively fixed in position within the eye. The ocular aberrations of the eye changed with increased accommodative demand, but not in a consistent manner among individuals. Those aberrations that appeared to be most affected were defocus, vertical primary and secondary astigmatism, vertical coma, horizontal and vertical primary and secondary trefoil, and spherical aberration.

CONCLUSIONS: Some of the reported near vision benefits of the Tetraflex accommodating IOL appear to be due to changes in the optical aberrations because of the flexure of the IOL on accommodative effort rather than forward movement within the capsular bag. [*J Refract Surg*. 2010;xx:xxx-xxx.]
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The Tetraflex (KH-3500; Lenstec, St Petersburg, Fla) intraocular lens (IOL) is one of the currently marketed accommodating IOLs, whose original proposed principal action was an anterior shift on contraction of the ciliary muscle.[1] However, the lens is designed to move as a whole in the capsular bag rather than through the hinge optics of IOLs such as the 1CU (1 Component Unit; HumanOptics AG, Erlangen, Germany).[1] Sanders and Sanders[2] described the Tetraflex IOL as having “extremely flexible 5° angulated closed-loop haptics,” finding the lens to provide enhanced near vision with good distance vision 6 months after surgery; however, no control group was examined.The same authors found that the Tetraflex allowed most of their patients (88%) to read newspaper and telephone directory print compared to 7% of those implanted with a monofocal IOL.[3] Our prior study on the Tetraflex IOL showed 0.39±0.53 diopters (D) of physiologic objective accommodation at 3 weeks after implantation, although this decreased slightly by 6 months.[1]

The mechanism of action of the first-generation accommodating IOLs is not fully understood. To address this issue, Marchini et al[4] studied patients implanted 6 months previously with the Crystalens AT-45 accommodative IOL (Bausch & Lomb, Rochester, NY). The range of eye focus that allowed

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Figure. Tetraflex intraocular lens (Lenstec, St Petersburg, Fla).

corrected distance visual acuity to be maintained (on average 1.10 D) on 3.30-D stimulation of the contralateral eye was correlated with a decrease in anterior chamber depth (r=0.40) and the ciliary–scleral process angle (r=0.77).[4] However, the Crystalens IOL differs substantially from the Tetraflex, as it has grooves in the surface of the plate adjacent to the optic that act as hinges. The authors also noted the possible contribution of gravity to the findings, as ultrasound biomicroscopy was performed with the patient supine. Most studies with these first-generation IOLs have found a forward shift on average with pharmacologically induced accommodation.[5] However, the results are variable with some eyes showing a backwards shift despite apparently good distance corrected near visual acuity, particularly with the Crystalens AT-45.[5] However, the Tetraflex has not been examined. In addition, pharmacologically induced lens movement has been shown to overestimate the anterior segment changes that can be utilized physiologically.[6]

Most aberrometers have a closed field-of-view and a fixed focal length target designed to relax accommodation to measure the distance viewing wavefront. Hence, they are unable to investigate any changes in wavefront with accommodative effort. An adapted instrument (dynamic stimulation aberrometry, Optana, attached to the WASCA; Carl Zeiss Meditec AG, Jena, Germany) has recently been used to demonstrate changes in aberrations over a range of focal distances in eight patients, one of whom was implanted with a dual-optic accommodating IOL (Synchrony; Visiogen, Irvine, Calif).[7] Unlike autorefractors and IOL biometry techniques, aberrometers offer the potential to investigate the optical effects of IOL flexure in vivo to attempts to focus at near.

This study examines the objective accommodation achieved in eyes implanted with an accommodating IOL (Lenstec Tetraflex KH-3500) compared with changes in pupil size, anterior chamber depth, and ocular aberrations.

PATIENTS AND METHODS

This study consisted of physiologic measurements of patients previously implanted with the Tetraflex IOL. Informed consent was obtained from patients prior to inclusion in the study after explanation of the nature and possible consequences of the study. The research followed the tenets of the Declaration of Helsinki and was approved by the Solihull Local Research Ethics Committee. Enrollment criteria were patients who had undergone routine cataract surgery to remove a lenticular opacity affecting their vision, no other eye disease or previous ocular surgery, no ocular surface problems or dry eye, no medication with known accommodative effects, and had been implanted with the Tetraflex IOL for at least 2 years.

The Tetraflex accommodating IOL is a single-piece, spherical optic, acrylic IOL with a refractive index of 1.46. The central optic portion is 5.75 mm and the overall size 11.5 mm in diameter. Its design is shown in the Figure.

Thirteen eyes of eight randomly selected patients aged 45 to 81 years (mean: 68.4±11.7 years) were assessed. Five eyes had been implanted with the Tetraflex IOL binocularly and 3 eyes monocularly. Retinoscopy and subjective refraction (maximum plus correction without a drop in visual acuity) was performed and all subsequent measures were taken with an optimum distance correction. Objective accommodative responses were assessed using the open-field NVisionK-5001 (Shin-Nippon Commerce Inc, Tokyo, Japan) through undilated pupils.[8] Zernike polynomial aberrations up to eighth order were measured using a Shack-Hartmann aberrometer (KR9000-PW; Topcon, Tokyo, Japan) modified to include a Badal optical system[9] and Maltese cross target. Dilation would have affected the accommodative response of patients and no patients had pupils <3 mm, therefore, aberrations were interpreted over a standardized 3-mm pupil. Patients were asked to blink before measurements to minimize potential tear film effects. Movement of the IOL (anterior chamber depth) and pupil size with attempted accommodation was determined with optical coherence tomography (OCT) (Visante; Zeiss, Oberkochen, Germany).[10] With each instrument, patients viewed a static 90% contrast Maltese cross located at 0.00, 0.50, 1.00, 2.00, 3.00, and 4.00 D accommodative demand through a Badal optical system.

TABLE

Correlation of the Average Aberrations With Increasing Accommodative Demand for Zernike Polynomial Coefficients in 13 Eyes Implanted With the Tetraflex Accommodating IOL

Zernike Term		Description	Correlation (r)	Significance
	−2	Astigmatism	−0.027	.959
2	0	Defocus	−0.913	.011*
	2	Astigmatism	−0.670	.145
	−3	Trefoil	−0.954	.003†
	−1	Coma	0.143	.788
3	1	Coma	−0.308	.553
	3	Trefoil	0.593	.215
	−4	Quadrafoil	0.570	.237
	−2	Secondary astigmatism	0.929	.007†
4	0	Spherical aberration	−0.680	.138
	2	Secondary astigmatism	0.881	.020*
	4	Quadrafoil	0.017	.975
	−5	Pentafoil	−0.821	.045*
	−3	Secondary trefoil	0.614	.194
	−1	Secondary coma	−0.948	.004†
5	1	Secondary coma	0.200	.703
	3	Secondary trefoil	0.678	.139
	5	Pentafoil	0.121	.820
	−6	Hexafoil	0.519	.291
	−4	Secondary quadrafoil	0.014	.979
	−2	Tertiary astigmatism	−0.449	.372
6	0	Secondary spherical aberration	−0.973	.001†
	2	Tertiary astigmatism	−0.788	.063
	4	Secondary quadrafoil	−0.135	.799
	6	Hexafoil	0.426	.399

Note. A negative correlation indicates the Zernike polynomial decreases with accommodative demand. A negative Zernike sign indicates vertical direction and a positive Zernike sign indicates horizontal direction.
*$P<.05$.
†$P<.01$.

To allow for individual differences among eyes, Pearson's correlation (r) of accommodative demand compared to Zernike coefficients, pupil size, and anterior chamber depth were calculated for each eye and averaged across the 13 eyes. Repeat measure analysis of variance was applied to the 10 repeated aberration Zernike coefficients at each accommodative demand for each eye to determine changes with accommodative effort.

RESULTS

The average time from implantation of the Tetraflex lens was 2.2±0.2 years (range: 2.0 to 2.8 years). As accommodative demand increased, pupil size decreased (r=−0.51±0.55; 0.62±0.41 mm) and anterior chamber depth increased (r=0.36±0.68; 0.02±0.05 mm). Maximal objective accommodation achieved over the accommodative demand range was 0.2±0.3 D (range: 0.0 to 1.0 D) as measured with the autorefractor.

The mean correlation across patients for each of the Zernike coefficients from second to eighth order over a 3-mm standard pupil size with increasing accommodative demand is displayed in the Table. The aberrations that on average were significantly correlated with accommodative demand were defocus (Z_2^0), vertical trefoil (Z_3^{-3}), vertical and horizontal secondary astigma-

TABLE CONTINUED

Correlation of the Average Aberrations With Increasing Accommodative Demand for Zernike Polynomial Coefficients in 13 Eyes Implanted With the Tetraflex Accommodating IOL

Zernike Term		Description	Correlation (r)	Significance
	−7	Heptafoil	−0.351	.495
	−5	Secondary pentafoil	−0.832	.040*
	−3	Tertiary trefoil	0.601	.207
7	−1	Tertiary coma	−0.795	.059
	1	Tertiary coma	0.548	.260
	3	Tertiary trefoil	−0.633	.177
	5	Secondary pentafoil	−0.703	.119
	7	Heptafoil	−0.583	.225
	−8	Septafoil	−0.280	.591
	−6	Secondary hexafoil	0.881	.020*
	−4	Tertiary quadrafoil	0.969	.001†
	−2	Quaternary astigmatism	−0.928	.008†
8	0	Tertiary spherical aberration	−0.973	.001†
	2	Quaternary astigmatism	0.886	.019*
	4	Tertiary quadrafoil	−0.085	.872
	6	Secondary hexafoil	0.700	.121
	8	Septafoil	−0.244	.642

Note. A negative correlation indicates the Zernike polynomial decreases with accommodative demand. A negative Zernike sign indicates vertical direction and a positive Zernike sign indicates horizontal direction.
*$P<.05$.
†$P<.01$.

tism (Z_4^{-2}, Z_4^2), vertical pentafoil (Z_5^{-5}), vertical secondary coma (Z_5^{-1}), secondary spherical aberration (Z_6^0), vertical secondary pentafoil (Z_7^{-5}), vertical secondary hexafoil (Z_8^{-6}), vertical tertiary quadrafoil (Z_8^{-4}), tertiary spherical aberration (Z_8^0), and vertical and horizontal quaternary astigmatism (Z_8^{-2}, Z_8^2).

Those aberrations that changed systematically with increased accommodative demand (mean across all patients r>0.30) were defocus (Z_2^0, r=−0.42±0.48), vertical astigmatism (Z_2^2, r=−0.38±0.61), horizontal trefoil (Z_3^{-3}, r=−0.48±0.42), vertical secondary astigmatism (Z_4^2, r=0.35±0.63), and horizontal secondary trefoil (Z_5^{-3}, r=0.30±0.60). Those aberrations that changed significantly at any level of accommodative effort in >60% of eyes were vertical astigmatism (Z_2^2), horizontal and vertical trefoil (Z_3^{-3}, Z_3^3), vertical coma (Z_3^1), horizontal and vertical secondary trefoil (Z_4^{-2}, Z_4^2), and spherical aberration (Z_4^0).

DISCUSSION

Determining the mechanism of action of accommodating IOLs when they only provide a small objective benefit in near performance is limited by the resolution of the techniques available to assess optical and biometric changes. It is further complicated by targets within the subjective depth of focus, resulting from the pupil aperture and static optical aberrations, providing no drive to accommodation. In addition, the accommodative system is principally driven by high frequency, high contrast targets.[11] Therefore, measured accommodation will increase within the range of objective optical change in focus available to the eye (once the depth of focus has been exceeded), but may decrease or become more variable above this level due to the resulting image blur. The analysis performed in this study used objective, sensitive techniques and examined both systematic effects over a range of accommodative demands and significant changes between these demands, regardless of accommodative level at which they occurred, to minimize these limitations.

Previous studies have noted a decrease in objective accommodation with time after implantation.[1,6,12-15] At 2 years after implantation, the Tetraflex accommodating IOL appears to be relatively fixed in position within the eye, moving backwards on increasing accommodative demand from 3.23±1.31 mm to 3.27±1.33 mm. Pupil size decreased from 4.5±1.7 mm to 3.9±1.6 mm over the same increase in accommodative demand, but the depth of focus of the eye is relatively constant with pupil sizes >2.5 mm.[16,17] The ocular aberrations of the eye changed with increased accommodative demand, but not in a consistent manner among individuals. In addition to the defocus Zernike term, which correlated with objective eye focus as determined by the autorefractor (mean across all patients, r=0.44), those aberrations that appeared to be most commonly affected by the accommodative demand of the stimulus viewed were vertical primary and secondary astigmatism, vertical coma, horizontal and vertical primary and secondary trefoil, and spherical aberration. These ocular aberrations may be particularly beneficial to a patient's near vision as vertical astigmatism and coma aberrations in eyes implanted with spherical IOLs have previously been found to be associated with spectacle independence.[18]

Flexure changes to the optics of the Tetraflex accommodating IOL appear to occur with accommodative effort and could be responsible for some of the previously shown near visual benefit of this IOL.

AUTHOR CONTRIBUTIONS

Study concept and design (J.S.W., L.N.D., S.A.N., G.A.G., S.S.); data collection (J.S.W., L.N.D., N.G., T.M., S.S.); interpretation and analysis of data (J.S.W., N.G., S.A.N., T.M., S.S.); drafting of the manuscript (J.S.W., S.S.); critical revision of the manuscript (J.S.W., L.N.D., N.G., S.A.N., G.A.G., T.M., S.S.); statistical expertise (J.S.W.); administrative, technical, or material support (J.S.W., N.G., T.M.); supervision (S.A.N., S.S.)

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