Evaluation of a satisfied bilateral scleral expansion band patient

Lisa A. Ostrin, Sanjeev Kasthurirangan, Adrian Glasser, PhD

Purpose: To measure accommodation subjectively and objectively in a satisfied bilateral scleral expansion band patient.

Setting: University of Houston, College of Optometry, Houston, Texas, USA.

Methods: One bilateral scleral expansion patient (age 50 years), 9 age-matched normal presbyopic control subjects (age range 48 to 52 years), and 1 normal control subject (age 27 years) participated. The scleral expansion patient had a complete eye examination, corneal topography, and wavefront measurements 19 months postoperatively. Accommodation was measured subjectively with the push-up technique, minus to blur, and dioptric range of clear vision. Accommodation was determined objectively by measuring the accommodative responses to negative lenses and pilocarpine 6% with a Hartinger coincidence refractometer and to real targets with a dynamic infrared optometer.

Results: Distance and near acuity of 20/20 was achieved with +1.00 diopter (D) in the left eye, +0.50 D in the right eye, and a near add of +2.25 D. Corneal topography and ocular aberration measurements revealed no suggestion of optical multifocality. Subjective measurements resulted in accommodative amplitudes of 1.50 to 4.00 D, and objective measurements resulted in amplitudes of 0.25 to 1.33 D. The PowerRefractor showed an accommodative response of 0.50 D to stimuli of 1.00 to 4.00 D and strong pupillary constriction with accommodative effort compared with the control.

Conclusions: No increase in accommodative amplitude above normal age-matched controls was found. Patient satisfaction may have come from the high expectations this patient had for a positive surgery outcome.

J Cataract Refract Surg 2004; 30:1445–1453 © 2004 ASCRS and ESCRS

Accommodation is a dioptric change in the power of the eye that occurs with an attempt to focus on near objects.[1] Amplitude of accommodation decreases with age in presbyopia,[2] and by age 55, little or no accommodative ability remains.[3] There are many optical interventions to increase near visual acuity after the onset of presbyopia, including spectacles and contact lenses. Surgical interventions include corneal refractive surgery and implantation of monovision and multifocal intraocular lenses (IOLs).[4,5] New procedures aimed at restoring dynamic accommodative ability include scleral expansion band surgery,[6] anterior ciliary sclerotomy[7,8] and accommodating IOLs.[9,10]

Scleral expansion surgery is based on Schachar's theory of accommodation,[11] which suggests that accommodation occurs when the ciliary muscle contracts to increase zonular tension, causing the lens equator to move toward the sclera, flattening the peripheral lens and increasing the volume and curvature of the central lens. According to Schachar et al.,[12] presbyopia occurs because of the increase in the equatorial diameter of the lens throughout life, which decreases extralenticular space and reduces zonular tension.

Schachar's theory contradicts the classically accepted Helmholtz theory, which states that accommodation occurs when the ciliary muscle contracts and moves toward

Accepted for publication December 11, 2003.

Reprint requests to Adrian Glasser, College of Optometry, University of Houston, 4901 Calhoun Rd, Houston, Texas 77204, USA. E-mail: aglasser@uh.edu.

Published by Elsevier Inc.

0886-3350/04/$–see front matter
doi:10.1016/j.jcrs.2003.12.055

the lens equator to release zonular tension.[13] This mechanism has been demonstrated in iridectomized rhesus monkeys[14] and in a human albino subject using iris transillumination.[15]

The scleral expansion band (SEB) procedure involves insertion of 4 poly(methyl methacrylate) (PMMA) bands into scleral tunnel incisions about 5.0 mm posterior to the limbus[16] to expand the sclera overlying the ciliary body, increasing the circumlental space. This is thought to increase the resting equatorial zonular tension so the zonules can pull on the lens equator under the Schachar theory of accommodation.

Schachar[16] has reported 5.80 to 11.11 diopters (D) of subjectively measured accommodative amplitude in postoperative scleral expansion patients. In an independent study, subjectively measured amplitude increased in 3 of 8 scleral expansion eyes 6 months postoperatively but returned to preoperative values in all eyes within a year.[17] Another study of 29 patients reports a mean increase in amplitude of 1.50 D $\pm$ 1.20 (SD) in the operated eyes and 1.30 $\pm$ 1.20 D in the unoperated control eye with the push-up test.[18] The high variability and increase in near visual ability of the unoperated eyes were attributed to the subjective nature of the testing, and the authors suggest that future studies incorporate objective measurements.

Subjective measurements of accommodation are inappropriate to assess the efficacy of accommodative restorative surgical procedures because of many confounding factors, including individual variation in blur sensitivity, ocular aberrations, and depth-of-focus.[19] Postoperative improvement in near visual acuity does not unequivocally demonstrate that accommodation is improved. True accommodative, optical changes in the eye must be measured objectively. Mathews[20] performed objective dynamic accommodative measurements on 3 postoperative scleral expansion patients and reports no evidence of accommodation.

Although scleral expansion surgery is suggested to restore accommodation, the surgery may enhance near vision through nonaccommodative means such as corneal multifocality or higher-order ocular aberrations. To understand whether true accommodation or functional near visual ability improves after scleral expansion surgery, subjective and objective, static and dynamic accommodation measurements, and other objective optical measures were performed on a satisfied bilateral SEB patient.

Subjects and Methods

Subjects

Postoperative testing was performed on a male bilateral SEB patient, aged 50 years. The patient presented to the University of Houston College of Optometry clinic for a routine eye examination 19 months after bilateral scleral expansion surgery, which had been performed outside the United States by a surgeon unaffiliated with the investigators. Accommodative measurements in this patient were compared with results obtained with the same methodology in 7 age-matched control subjects (age range 48 to 52 years) with similar iris color.[21,22] Shack-Hartmann wavefront analysis was performed on the SEB patient and 2 presbyopic control subjects (aged 52 years), and PowerRefractor (MultiChannel Systems) measurements were performed on the SEB patient and 1 young control subject (aged 27 years). All procedures were performed with informed consent under an institutionally approved human subjects protocol.

Procedures

At the SEB patient's first visit, a complete dilated eye examination including corneal topography with the Orbscan (Orbtek) and wavefront measurements with a custom-built Shack-Hartmann wavefront aberrometer were performed.[23] Wavefront aberrations were recorded when the eyes were dilated and cyclopleged. Five images of each eye were captured and analyzed for 3.0 mm, 5.0 mm, and 7.0 mm entrance pupil sizes.[24] Corneal topography and ocular wavefront aberrations were evaluated for evidence of multifocality. A through-focus simulation using MatLab (MathWorks, Inc.) was performed for each eye, ranging in defocus from +2.00 D to −3.00 D in 0.50 D steps.[25] The Strehl ratio, a measure of image quality, was calculated from Shack-Hartmann measurements as a function of defocus. The depth-of-focus was computed as the full-width half-max of the Strehl ratio versus defocus.

Accommodative measurements were made on 2 subsequent visits 42 days and 148 days after the eye examination. Accommodation was assessed in the right eye on the first visit and in the left eye on the second visit by 3 subjective and 3 objective methods. Methods used to measure accommodation have been described.[22] Subjective monocular accommodative amplitude was measured with the push-up technique,[26] minus to blur, and the focometer (InFocus).[27] Objective accommodative amplitude was measured statically with a Hartinger coincidence refractometer (Zeiss)[28−31] when accommodation was stimulated with negative lenses and pilocarpine 6% and dynamically with an infrared optometer (PowerRefractor)[32−35] when stimulated with real targets. Due to a strong accommodative pupillary constriction and the PowerRefractor requirement for pupils larger than 3.0 mm, it was necessary to instill 2 drops of phenylephrine 2.5% to dilate the iris without cycloplegia. The PowerRefractor

Table 1. Uncorrected near visual acuity in the SEB patient at various dates from the patient's clinical ocular records as well as from the current study. The surgeon used a combination of Jaeger notation and Snellen notation in the chart.

Date	Right Eye	Left Eye
Preoperative	J16 (apprx. 20/120)	J5 (apprx. 20/45)
Postoperative		
1 day	20/60	20/50
2 days	20/70	20/50
4 days	20/20	20/20
17 days	J2 (apprx. 20/30)	$J1^-$ (apprx. 20/25)
71 days	J7 (apprx. 20/60)	$J2^+$ (apprx. 20/30)
570 days (current study)	20/100	20/70

measurements were recorded in the same way for 1 phenylephrine-dilated 27-year-old control subject.

Results

The SEB patient reported to be relieved of reading glasses after the scleral expansion procedure except when very tired or after long periods of not performing eye exercises. "Massive headaches" occurred for 2 weeks after the scleral expansion procedure with effort to focus on a near object. Uncorrected Snellen visual acuities were 20/20 in the right eye and 20/30 in the left eye at distance (6 m) and 20/100 in the right eye and 20/70 in the left eye at near (40 cm). Preoperative and postoperative near visual acuities recorded at the surgeon's office in follow-up visits are given in Table 1.

The patient had simple hyperopia of +1.00 D in the right eye and +0.50 D in the left eye with presbyopia. An add power of +2.25 D in both eyes was found with fused cross-cylinder and balance of positive and negative relative accommodation. With this correction in place, the patient achieved 20/20 distance and near visual acuity. He had normal intraocular pressure and no ocular pathology. Anterior segment examination showed 4 readily visible, blue–gray protuberances indicating the scleral bands inserted in the 4 quadrants of each eye that appeared to be well healed (Figure 1). The protuberance of the bands varied considerably, from almost flush with the surface of the sclera to very prominent. No evidence of scleral erosions was present.

Orbscan corneal topography was performed on both eyes (Figure 2, *A*). The right eye had a maximum power of 44.2 D (158 degrees) and a minimum power of 43.5 D (68 degrees), with a mean power of 43.8 D at the 3.0 mm zone. The left eye had a maximum power of 43.8 D (57 degrees) and a minimum power of 43.3 D (147 degrees), with a mean power of 44.0 D at the 3.0 mm zone. There was no indication of systematic topographical features associated with the 4 quadrants at which the bands were located.

Gross evaluation of the Shack-Hartmann wavefront profile showed no patterns or irregularities that could be directly attributed to the insertion of the scleral bands in either eye (Figure 2, *B*). The through-focus simulation resulted in a depth-of-focus of 1.0 to 1.5 D from infinity (Figure 3, *A* and *B*). For myopic defocus greater than −1.5 D, the Strehl ratio approached zero. These results were similar to the results in the 2 normal presbyopic controls (Figure 3, *C* and *D*).

Maximum accommodative amplitude found with the various methods of measurement of the SEB patient's right and left eyes, along with 7 age-matched normal controls, is shown in Figure 4, *A*. Figure 4, *B* shows changes in accommodation with time after pilocarpine instillation.

Dynamic accommodative responses recorded with the PowerRefractor resulted in a maximum amplitude in both eyes of 0.45 D (right eye, Figure 5, *A*). A strong near pupillary response occurred with stimuli of 2.00 D or greater (Figure 5, *B*; Table 2). The dynamic accommodative and pupil responses for the 27-year-old control subject recorded with the PowerRefractor are shown in Figure 5, *A* and *B* (bottom panels). Accommodative stimulus response curves are shown for both eyes of the SEB patient in Figure 5, *C*.

Discussion

All accommodation measurements showed that the amplitude of the satisfied SEB patient was within a normal range for his age. Compared with subjective methods, the objective methods resulted in lower accommodative amplitudes in the SEB patient and the controls, demonstrating overestimation of accommodation with subjective methods.[36]

Dynamic recordings with the objective infrared optometer showed about 0.45 D of accommodation in each eye of the SEB patient. Paradoxically, a small hyperopic shift was noted for a 3.00 D accommodative

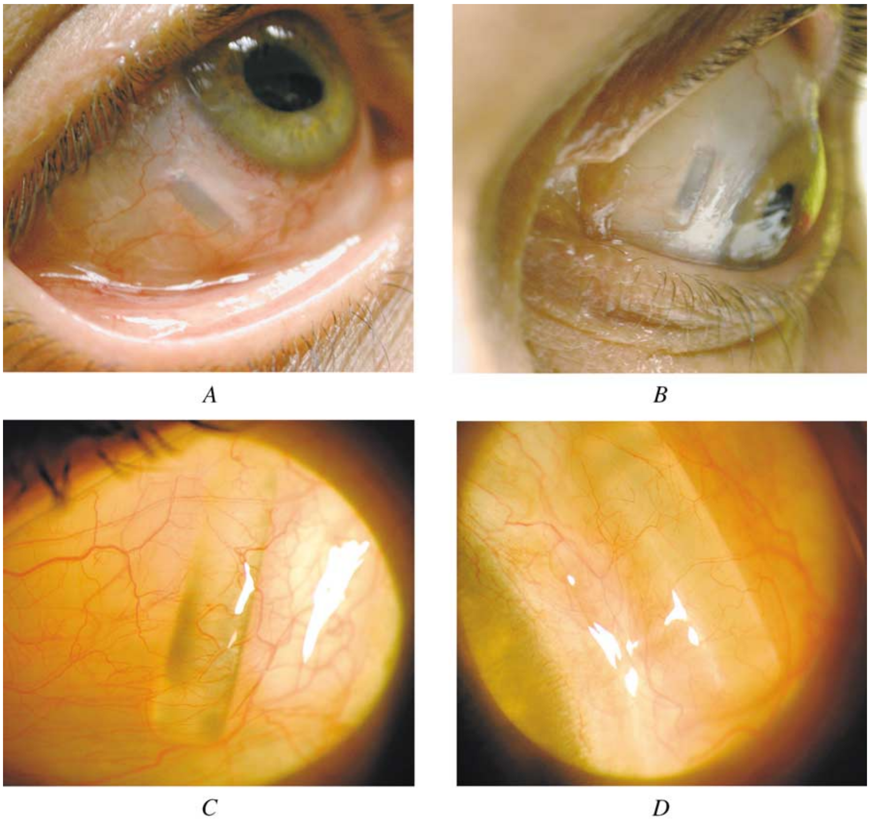

Figure 1. (Ostrin) Slitlamp photographs of the PMMA bands at 7:30 in the right eye (*A*) and 10:30 in the left eye (*B*). Higher-magnification slitlamp photographs are shown at 10:30 (*C*) and 1:30 (*D*).

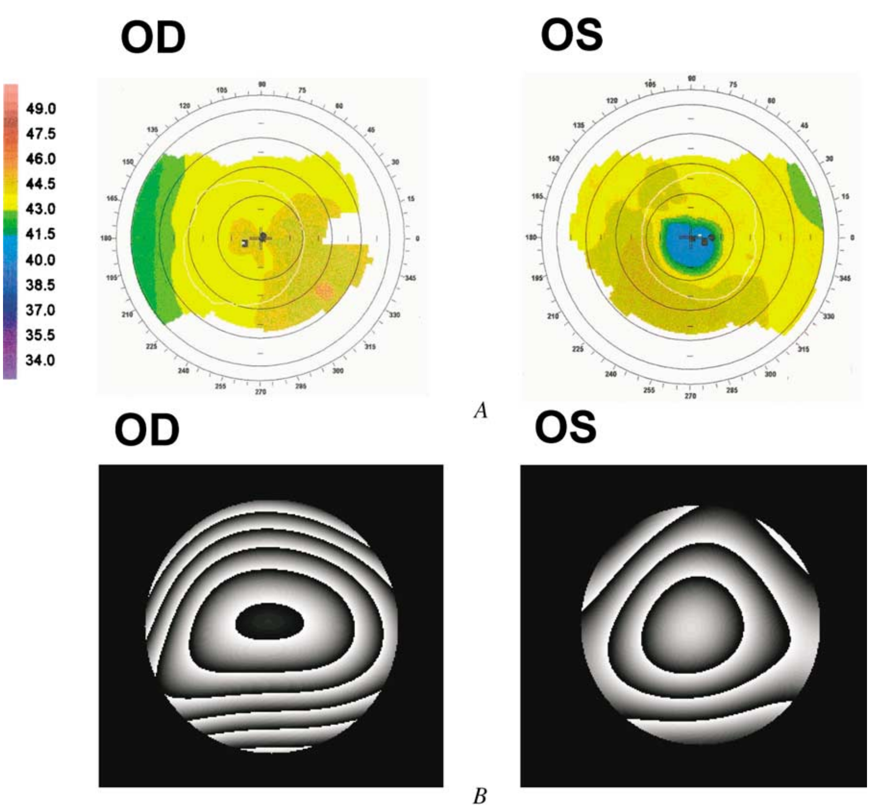

Figure 2. (Ostrin) Corneal topography measured with Orbscan, analyzed over a 3.0 mm zone (*A*) and wavefront profile calculated from the Shack-Hartmann wavefront images analyzed for 3.0 mm and 5.0 mm pupil sizes (*B*) do not show significant local variations that might contribute to multifocality.

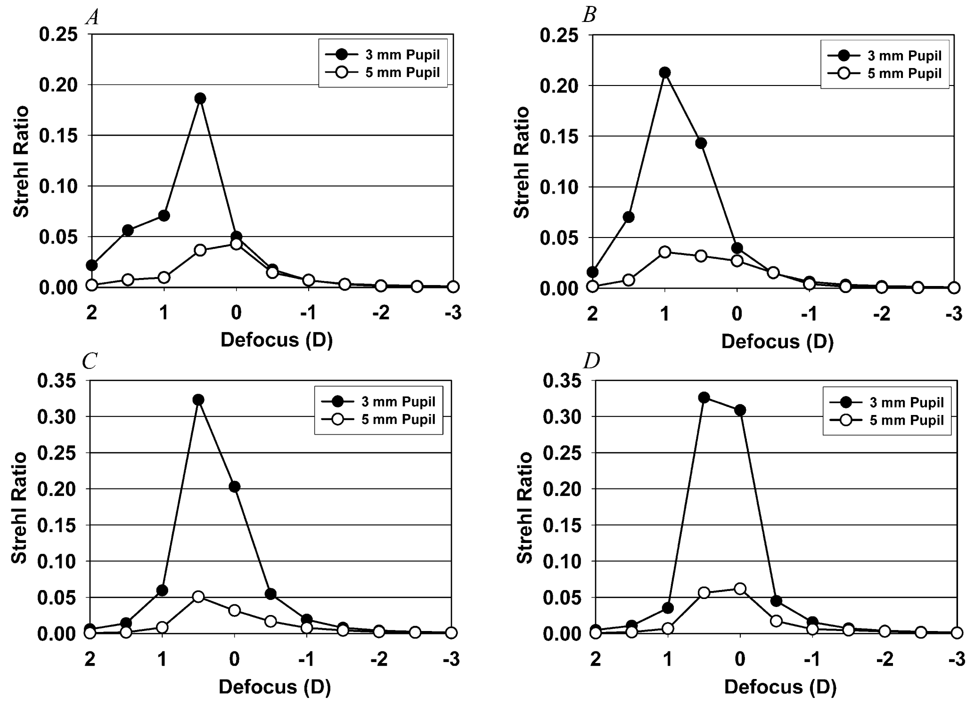

Figure 3. (Ostrin) Through-focus simulation for 3.0 mm and 5.0 mm entrance pupil diameters in the right and left eyes of the SEB patient (*A* and *B*) and in 1 eye each of 2 age-matched normal controls (*C* and *D*). The peak Strehl ratio occurs at the dioptric defocus with the best image quality. A broad peak indicates increased depth-of-field. No systematic differences were noted between the patient and the controls to suggest an increased depth-of-focus in the SEB patient.

stimulus in the right eye. The patient clearly made an accommodative effort to this stimulus, as the pupil showed a consistent accommodative constriction of 1.0 to 2.0 mm for each near target presentation. It is unclear why a hyperopic shift should have occurred for the higher amplitude stimuli. This could have been due to instrument artifact, but it clearly indicates that no accommodation occurs.

It is of interest to use other objective measurement techniques to assess whether near vision might be improved through nonaccommodative means such as increased corneal or noncorneal ocular aberrations. Corneal topography of the SEB patient showed little astigmatism (less than 0.8 D); the astigmatism did not show a pattern implicating an association with the SEBs. There were no local areas of increased corneal power

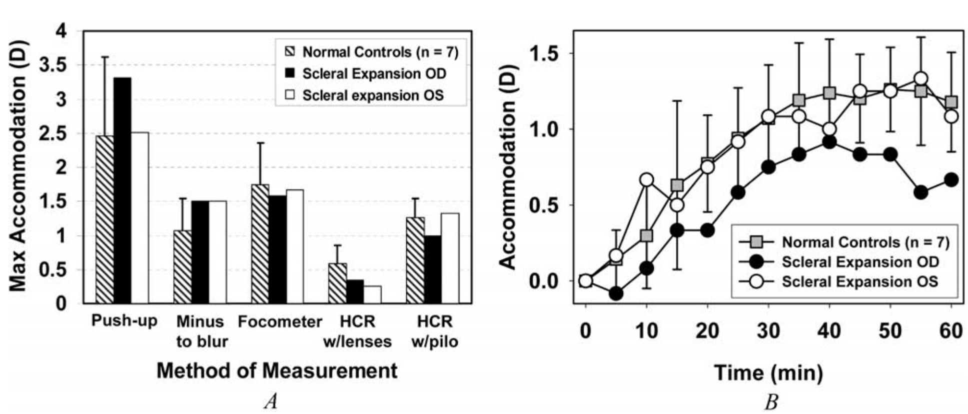

Figure 4. (Ostrin) *A:* Maximum accommodative amplitude (D) for the various methods of measurement in the right and left eyes of the SEB patient and in the right eyes of 7 age- and iris color-matched normal presbyopic controls (error bars represent SD in the control subjects). *B*: Change in accommodation (D) with time as measured with a Hartinger coincidence refractometer after instillation of pilocarpine 6% in the right and left eyes of the SEB patient compared with 7 age- and iris color-matched normal presbyopic controls (error bars represent SD).

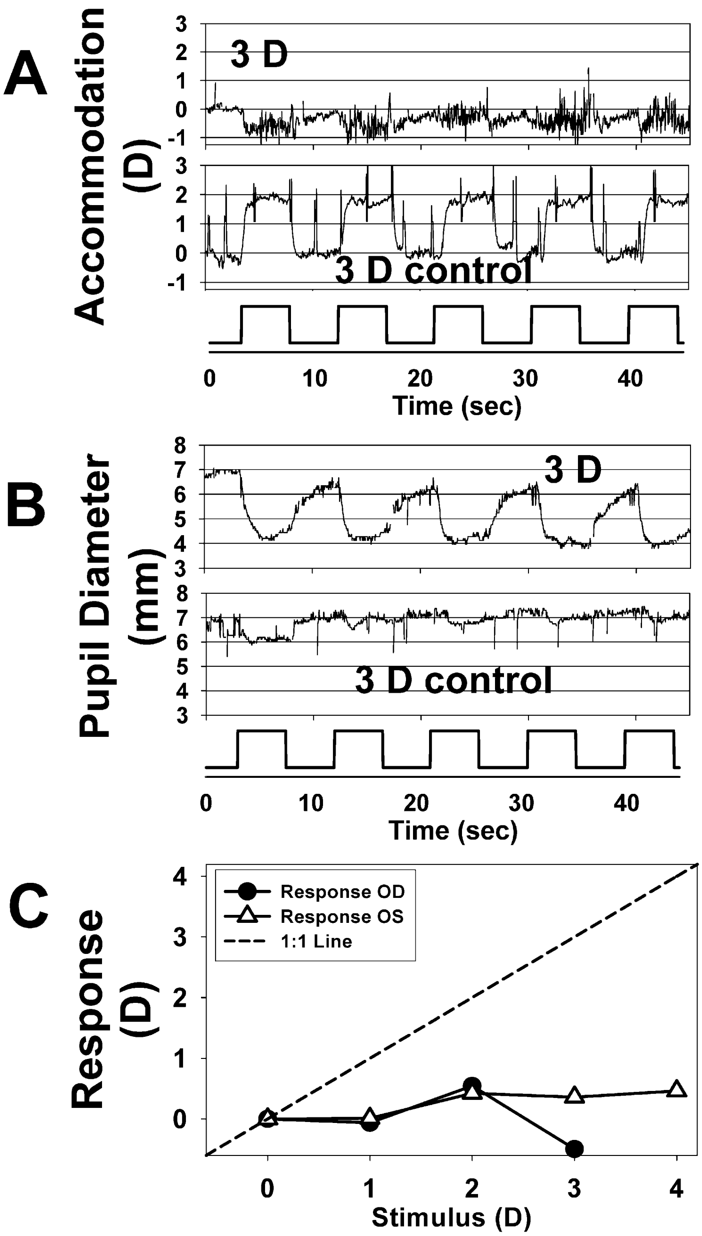

Figure 5. (Ostrin) Accommodation (D) (*A*) and pupil responses (mm) (*B*) measured with the PowerRefractor in the right eye of the SEB patient (*A* and *B*: upper panel) and the 27-year-old control subject (*A* and *B*: lower panel) to a 3.0 D stimulus. Vertical spikes in the traces represent blinks. The square wave plot below *A* and *B* represents the far–near stimulus presentation. *C*: Accommodative stimulus response curves obtained from the PowerRefractor dynamic measurements in the right and left eyes of the SEB patient.

that would lead to the suggestion of corneal optical multifocality.

McLeod[37] evaluated the preoperative and postoperative ocular wavefront profiles of 3 scleral expansion patients who experienced improvement in near reading ability. He found no change in higher-order aberrations that might suggest optical multifocality. The wavefront profiles of our SEB subject showed no suggestion of multifocality. It has been demonstrated that the Strehl ratio is well correlated with subjective psychophysical approximations of the visual performance for moderate amounts of defocus.[38] The simulation in our study showed that the SEB patient's aberrations did not lead to multifocality or an increased depth-of-focus that would suggest a basis for an increase in near visual acuity.

Historically, it has been suggested that presbyopia occurs because of an age-related increase in lenticular sclerosis.[39,40] Schachar[16] has proposed that presbyopia occurs because of an age-related decrease in zonular tension. In vitro studies show that the human lens loses the ability to undergo accommodative changes with age[41] and becomes harder and more resistant to compressive forces.[42] In vivo magnetic resonance imaging shows no age-related increase in lens diameter in the unaccommo-

Table 2. Accommodation and pupil constriction measured by the PowerRefractor in the SEB patient and the 27-year-old control subject. The patient exhibits a strong pupillary response with the effort to focus on near objects.

Subject	Measurement	1 D Stimulus	2 D Stimulus	3 D Stimulus	4 D Stimulus
SEB patient					
Right eye	Accommodation (D)	0.10 ± 0.11	0.45 ± 0.32	−0.59 ± 0.28	NA
	Pupil response (mm)	0.56 ± 0.18	1.32 ± 0.44	2.22 ± 0.42	NA
Left eye	Accommodation (D)	0.05 ± 0.03	0.31 ± 0.18	0.25 ± 0.17	0.35 ± 0.22
	Pupil response (mm)	0.03 ± 0.01	0.72 ± 0.19	1.02 ± 0.29	0.80 ± 0.13
Control subject					
Right eye	Accommodation (D)	0.65 ± 0.03	1.39 ± 0.08	2.32 ± 0.05	3.32 ± 0.10
	Pupil response (mm)	0.06 ± 0.02	0.25 ± 0.19	0.84 ± 0.15	1.14 ± 0.08

Mean ± SD
NA = not available; SEB = scleral expansion band

dated eye.[43] This evidence suggests that surgical expansion of the sclera cannot restore accommodative capacity to the crystalline lens.[41] Similarly, anterior ciliary sclerotomy (ACS) and modification with silicone expansion plugs (SEPs)[8] also rely on expansion of the sclera to restore accommodative ability. Subjective measurements of ACS patients show no increase in accommodation.[7] While there have been no published peer-reviewed studies of objective measurements of accommodation after the ACS–SEP procedure, scleral expansion with SEB, ACS, or ACS–SEP cannot restore the accommodative capacity to the presbyopic crystalline lens.

Results in this study do not explain why this patient is satisfied with the scleral expansion procedure. Postoperative accommodation exercises and pilocarpine 1% are suggested to improve accommodation after scleral expansion surgery to overcome ciliary muscle atrophy from disuse.[44] It is unlikely that the ciliary muscles in presbyopic eyes suffer from atrophy or disuse. It is well established that accommodation and pupil constriction are coupled with convergence. Every convergence response a presbyopic patient makes, even with near-vision correction in place, would result in a consensual ciliary muscle contraction and pupil constriction but with no effect on the presbyopic lens. It has been demonstrated that ciliary muscle contraction still occurs in presbyopic patients when they make an accommodative effort.[43] The PowerRefractor-measured dynamic pupil constrictions show that an accommodative effort was made by the SEB patient to a near stimulus.

Ideally, to establish whether scleral expansion restores accommodation, controlled clinical trials should be done in which objective testing is performed preoperatively and postoperatively in many subjects. Despite repeated published requests to perform objective testing on scleral expansion patients,[37,45,46] we and others familiar with objective accommodation testing have not had access to patients. The comparison with control subjects is an appropriate alternative, although not ideal, and should not be considered a substitute for doing the preoperative measurements when they can be done. The maximum amplitude of 1.33 D that we were able to record with objective techniques is comparable to the amplitudes in age-matched controls and is somewhat less than the 5.80 to 11.11 D that some suggest can be restored with scleral expansion.[16] This study demonstrates possible approaches available for objective assessments of accommodation that have not been used in published studies.[7,17,18]

References

1. Keeney AH, Hagman RE, Fratello CJ. Dictionary of Ophthalmic Optics. Newton, MA, Butterworth-Heinemann, 1995; 4
2. Duane A. Normal values of the accommodation at all ages. JAMA 1912; 59:1010–1013
3. Hamasaki D, Ong J, Marg E. The amplitude of accommodation in presbyopia. Am J Optom 1956; 33:3–14
4. Javitt JC, Steinert RF. Cataract extraction with multifocal intraocular lens implantation; a multinational clinical trial evaluating clinical, functional, and quality-of-life outcomes. Ophthalmology 2000; 107:2040–2048
5. Greenbaum S. Monovision pseudophakia. J Cataract Refract Surg 2002; 28:1439–1443

6. Engelman CJ, Manche EE. Scleral expansion band surgical technique. In: Agarwal A, ed, Presbyopia: a Surgical Textbook. Thorofare, NJ, Slack, 2002; 109–111
7. Hamilton DR, Davidorf JM, Maloney RK. Anterior ciliary sclerotomy for treatment of presbyopia; a prospective controlled study. Ophthalmology 2002; 109:1970-1976; discussion by RF Steinert, 1976–1977
8. Fukasaku H. Anterior ciliary sclerotomy with silicone expansion plug implantation; effect on presbyopia and intraocular pressure. In: Agarwal A, ed, Presbyopia: a Surgical Textbook. Thorofare, NJ, Slack, 2002; 123–126
9. Cumming JS, Slade SG, Chayet A. Clinical evaluation of the model AT-45 silicone accommodating intraocular lens; results of feasibility and the initial phase of a Food and Drug Administration clinical trial; the AT-45 Study Group. Ophthalmology 2001; 108:2005–2009; discussion by TP Werblin, 2010
10. Kuchle M, Nguyen NX, Langenbucher A, et al. Implantation of a new accommodative posterior chamber intraocular lens. J Refract Surg 2002; 18:208–216
11. Schachar RA, Huang T, Huang X. Mathematical proof of Schachar's hypothesis of accommodation. Ann Ophthalmol 1993; 25:5–9
12. Schachar RA, Black TD, Kash RL, et al. The mechanism of accommodation and presbyopia in the primate. Ann Ophthalmol 1995; 27:58–67
13. Helmholtz H. Mechanism of accommodation. In: Southall JPC, ed, Helmholtz's Treatise on Physiological Optics; translated from the third German edition. New York, NY, Dover, 1962; 143–173
14. Glasser A, Kaufman PL. The mechanism of accommodation in primates. Ophthalmology 1999; 106:863–872
15. Wilson RS. Does the lens diameter increase or decrease during accommodation? Human accommodation studies: a new technique using infrared retro-illumination video photography and pixel unit measurements. Trans Am Ophthalmol Soc 1997; 95:261–267; discussion, 267–270
16. Schachar RA. Cause and treatment of presbyopia with a method for increasing the amplitude of accommodation. Ann Ophthalmol 1992; 24:445–447, 452
17. Malecaze FJ, Gazagne CS, Tarroux MC, Gorrand J-M. Scleral expansion bands for presbyopia. Ophthalmology 2001; 108:2165–2171
18. Qazi MA, Pepose JS, Shuster JJ. Implantation of scleral expansion band segments for the treatment of presbyopia. Am J Ophthalmol 2002; 134:808–815
19. Atchison DA, Charman WN, Woods RL. Subjective depth-of-focus of the eye. Optom Vis Sci 1997; 74: 511–520
20. Mathews S. Scleral expansion surgery does not restore accommodation in human presbyopia. Ophthalmology 1999; 106:873–877
21. Seddon JM, Sahagian CR, Glynn RJ, et al. Evaluation of an iris color classification system. Invest Ophthalmol Vis Sci 1996; 31:1592–1598
22. Ostrin LA, Glasser A. Accommodation measurements in a prepresbyopic and presbyopic population. J Cataract Refract Surg 2004; 30:1435–1444
23. Liang J, Grimm B, Goelz S, Bille JF. Objective measurement of wave aberrations of the human eye with the use of a Hartmann-Shack wave-front sensor. J Opt Soc Am A 1994; 11:1949–1957
24. Liang J, Williams DR. Aberrations and retinal image quality of the normal human eye. J Opt Soc Am A 1997; 14:2873–2883
25. Martin J, Roorda A. Predicting and assessing visual performance with multizone bifocal contact lenses. Optom Vis Sci 2003; 80:812–819
26. London R. Amplitude of accommodation. In: Eskridge JB, Amos JF, Bartlett JD, eds, Clinical Procedures in Optometry. Philadelphia, JB Lippincott, 1991; 69–71
27. Berger IB, Spitzberg LA, Nnadozie J, et al. Testing the FOCOMETER—a new refractometer. Optom Vis Sci 1993; 70:332–338
28. Fincham EF. The coincidence optometer. Proc Phys Soc (Lond) 1937; 49:456–468
29. Koretz JF, Neider MW, Kaufman PL, et al. Slit-lamp studies of the rhesus monkey eye. I. Survey of the anterior segment. Exp Eye Res 1987; 44:307–318
30. Koretz JF, Kaufman PL, Neider MW, Goeckner PA. Accommodation and presbyopia in the human eye. 1. Evaluation of in vivo measurement techniques. Appl Opt 1989; 28:1097–1102
32. Croft MA, Oyen MJ, Gange SJ, et al. Aging effects on accommodation and outflow facility responses to pilocarpine in humans. Arch Ophthalmol 1996; 114: 586–592
32. Gekeler F, Schaeffel F, Howland HC, Wattam-Bell J. Measurement of astigmatism by automated infrared photoretinoscopy. Optom Vis Sci 1997; 74:472–482
33. Schaeffel F, Wilhelm H, Zrenner E. Inter-individual variability in the dynamics of natural accommodation in humans: relation to age and refractive errors. J Physiol 1993; 461:301–320
34. Choi M, Weiss S, Schaeffel F, et al. Laboratory, clinical, and kindergarten test of a new eccentric infrared photorefractor (PowerRefractor). Optom Vis Sci 2000; 77:537–548
35. Kasthurirangan S, Vilupuru AS, Glasser A. Amplitude dependent accommodative dynamics in humans. Vision Res 2003; 43:2945–2956
36. Rosenfield M, Cohen AS. Repeatability of clinical measurements of the amplitude of accommodation. Ophthalmic Physiol Opt 1996; 16:247–249
37. McLeod SD. The challenge of presbyopia [editorial]. Arch Ophthalmol 2002; 120:1572–1574

38. Villegas EA, González C, Bourdoncle B, et al. Correlation between optical and psychophysical parameters as a function of defocus. Optom Vis Sci 2002; 79:60–67
39. Gullstrand A. The mechanism of accommodation. In: Southall JPC, ed, Helmholtz's Treatise on Physiological Optics. New York, NY, Dover, 1962; vol 1:382–415
40. Fisher RF. Presbyopia and the changes with age in the human crystalline lens. J Physiol (Lond) 1973; 228: 765–779
41. Glasser A, Campbell MCW. Presbyopia and the optical changes in the human crystalline lens with age. Vision Res 1998; 38:209–229
42. Glasser A, Campbell MCW. Biometric, optical and physical changes in the isolated human crystalline lens with age in relation to presbyopia. Vision Res 1999; 39:1991–2015
43. Strenk SA, Semmlow JL, Strenk LM, et al. Age-related changes in human ciliary muscle and lens: a magnetic resonance imaging study. Invest Ophthalmol Vis Sci 1999; 40:1162–1169
44. Soloway BD. Ultrasound biomicroscopy after scleral expansion band surgery and postoperative exercises. In: Agarwal A, ed, Presbyopia: A Surgical Textbook. Thorofare, NJ, Slack, 2002; 113–117
45. Kaufman PL. Scleral expansion surgery for presbyopia [guest editorial]. Ophthalmology 2001; 108:2161–2162
46. Steinert RF. Discussion of Anterior ciliary sclerotomy for treatment of presbyopia. A prospective controlled study. Ophthalmology 2002; 109:1976–1977

From the College of Optometry, University of Houston, Houston, Texas, USA.

Presented in part at the annual meeting of the American Academy of Optometry, San Diego, California, USA, December 2002.

Supported in part by a grant from Pharmacia (Glasser), NIH grant 1 RO1 EY014651-01 (Glasser), NEI grant EYO 7088-15 to the University of Houston, College of Optometry, and from the University of Texas Health Science Center at Houston, NEI grant 5 T32 EY07024-23 (Glasser, Ostrin).

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

Austin Roorda, PhD, and Ray Applegate, OD, PhD, assisted with aberration measurements and analysis. In Focus, Houston, Texas, USA, provided the focometer, and MultiChannel Systems, Reutlingen, Germany, provided the PowerRefractor.