articles

Subjective and objective measurement of human accommodative amplitude

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Purpose: To assess objective and subjective methods to measure accommodation in a young human population.

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

Methods: Accommodation was measured in the right eye of 15 young subjects (9 women and 6 men) whose ages ranged from 23 to 28 years and 1 36-year-old subject. The mean age of all subjects was 26 years. Accommodation was stimulated and measured with 4 techniques. Two subjective measures (focometer and minus-lens procedures) were used. Accommodation was also stimulated with minus-lens-induced blur and with pilocarpine 6% and measured objectively with a Hartinger coincidence refractometer.

Results: Accommodative amplitudes measured with the 2 subjective methods agreed with each other but differed from the objectively measured amplitudes. Objectively measured accommodative amplitudes were similar in all subjects, with a mean of about 7.0 diopters. Accommodation stimulated with pilocarpine reached a maximum 33 minutes after administration. Individuals with light irides showed a stronger accommodative response to pilocarpine than subjects with dark irides.

Conclusions: Subjective measures of accommodation tend to overestimate true accommodative amplitude. Methods exist to measure accommodation objectively. These include stimulating accommodation with trial lenses or pilocarpine 6% and measuring the accommodative response with an objective optometer such as a Hartinger coincidence refractometer. Objective measures of accommodation should be used to determine whether accommodation can be restored in presbyopes.

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Accommodation is an increase in the dioptric power of the eye that enables the image of near objects to be focused on the retina. An increase in the optical power of the eye occurs because of an increase in the anterior and posterior surface curvatures of the crystalline lens resulting from contraction of the ciliary muscles.[1,2] The functional significance of active accommodation is evident from the inconvenience that results from its gradual age-related loss in presbyopia. As patients develop presbyopia, they present clinically with difficulty in near-vision tasks. These problems manifest earliest in hyperopes and in emmetropes at about 40 years of age, when the accommodative reserve becomes insufficient to focus on near objects. However, the loss of accommodative amplitude begins early in life[3] and progresses to about age 55, when accommodation, as measured objectively, is completely lost.[4]

Accurate and objective measurement of accommodative amplitude is increasingly important as new surgical procedures claim to restore accommodation in presbyopes with scleral-expansion surgical procedures[5] or replacement of the cataractous crystalline lens with

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so-called accommodating intraocular lenses (IOLs).[6] Claims that accommodation is restored by these procedures are supported by subjective measurements only.[5–8] When appropriate objective measurements are made in scleral-expansion patients, no evidence of accommodation exists.[9] Recent reports using only subjective accommodation tests suggest that accommodation is not restored.[10]

If surgical procedures aimed at restoring accommodation or accommodating IOLs are to be shown to restore accommodation, accommodation must be measured objectively. Subjective assessment of near vision may suggest that accommodation is present when it is not. Explanations of this include the possibility of subjects learning near-acuity charts with repeated training and testing, increased depth of field in the eye that results from small pupil diameters, and the possibility that surgical procedures introduce aberrations such as astigmatism or multifocality to the eye.[11] For example, presbyopes with multifocal contact lenses or cataract patients with multifocal IOLs may have reasonably good distance and near acuity. When accommodation is measured subjectively in these patients, it may appear that they can accommodate. However, functional near and distance vision due to multifocality is not accommodation.

Objective tests of accommodation, ie, measurement of the change in the optical power of the eye, can differentiate true accommodation from pseudoaccommodation or other possible confounding factors. The ongoing debate over whether scleral-expansion procedures or accommodating IOLs can actually restore accommodation in presbyopes is pointless without appropriate objective accommodation measurements.[12]

Although it has been suggested that pilocarpine is an appropriate method to objectively stimulate accommodation when the response is measured with an objective optometer,[12] to our knowledge only 1 paper has done this. Croft et al.[13] measured the accommodative response to pilocarpine 2% and 6% with a refractometer, but only at 60 minutes after pilocarpine administration. Other studies have measured pilocarpine-stimulated changes in anterior chamber depth and lens thickness with A-scan ultrasound,[14–17] accommodative changes in lens diameter,[18] and accommodative movements of the IOL.[19–22] Several studies have measured the accommodative response to topical pilocarpine using subjective tests[15,17,23]; however, the amplitudes measured substantially overestimated actual dioptric change because of the small pupil diameters that result from pilocarpine stimulation. The time course and maximum amplitude of accommodation have not been determined and cannot be known unless refraction is measured repeatedly with an objective technique at short intervals after pilocarpine administration.

The most widely used clinical method of assessing accommodative amplitude is the subjective push-up test.[3] This requires a subject who is corrected for best distance vision to move a near reading target toward the eyes and report when the text is no longer in sharp focus. The reciprocal in meters of the distance from the eyes to the near reading chart represents the accommodative amplitude. Previous studies have tested the accuracy of the push-up method and shown that depth of focus, target size, illumination, end-point criteria, proximal cues, pupil size, and subject variability affect the outcome of the measurement, generally overestimating true accommodative amplitude.[24–27]

Numerous studies have compared methods of assessing accommodative amplitude. However, there are objective methods of stimulating and measuring accommodation that have not been systematically studied. In this study, we compared several subjective and objective methods of stimulating and measuring accommodation in young subjects to understand their benefits and drawbacks. Two instruments were used to measure accommodation. The focometer (InFocus) is a monocular, handheld, adjustable Badal optometer. It is used like a telescope and has a manual focusing ring, as on a camera lens, that allows the spherical optical power to be increased or decreased. A linear scale inscribed on the focusing ring allows the spherical power to be recorded in 0.25 diopter (D) steps.[28] The focometer is used to simultaneously stimulate and measure accommodation, but it requires subjective evaluation of defocus by the subject. The Hartinger coincidence refractometer (Zeiss) is an objective optometer based on the Schiener principle.[29] It requires a subjective vernier alignment task by the examiner but is totally objective with respect to the subject and accurate to within 0.25 D in a variable-focus model eye (Heine). This instrument has been widely used to measure accommodation stimulated in a variety of ways in animals[2,30,31] and humans.[13,32,33] The Hartinger is ideally suited to measure through small pupils (1.0 to 2.0 mm in diameter).

The focometer and minus-power trial lenses stimulate accommodation by introducing increasingly negative optical power to the eye, which the subject interprets as blur. Other methods must be used to stimulate accommodation when it is measured with the Hartinger. Negative-power trial lenses and pilocarpine 6% are used to subjectively and objectively stimulate accommodation.

The purpose of this study was to compare several methods of stimulating and measuring accommodation in young subjects to identify an appropriate objective method that can be used to determine whether surgical procedures can restore accommodation in presbyopes.

Subjects and Methods

Subjects

Fifteen young white subjects from the College of Optometry student body (9 women and 6 men) whose ages ranged from 23 to 28 years and a 36-year-old white subject participated; the mean age of all students was 26 years. Informed consent was obtained in accordance with institutionally reviewed and approved human subject protocols. All subjects were in good physical health and had refractive errors between +2.0 D and −2.0 D with less than 0.5 D of astigmatism. Exclusion criteria included anisometropia; amblyopia; and a history of ocular injury, ocular surgery, or ocular disease. Subjects were questioned regarding medical conditions or current medications that might be contraindicated with the use of topical pilocarpine, phenylephrine, or cyclopentolate. Each subject had a dilated fundus examination within 3 months of participation in the study. The study was performed under the guidance of the clinic director, who was a physician.

Procedures

Four methods, 2 subjective and 2 objective, were used to measure accommodation monocularly in the right eye of each subject. Accommodative amplitude was first determined subjectively using 2 methods: (1) the dioptric difference between distance correction and the maximum negative-power trial lens that could be cleared with accommodation and (2) the difference between distance correction and the maximum negative power introduced by the focometer that could be cleared with accommodation. Accommodative amplitude was then measured objectively using a Hartinger coincidence refractometer when accommodation was stimulated with (3) negative-power trial lenses placed in front of the left (contralateral) eye to stimulate consensual accommodation, which was measured in the right eye, or (4) topical application of 1 drop of pilocarpine 6% applied to the right eye to stimulate accommodation.

Before accommodation measurement, distance visual acuity was recorded monocularly in both eyes of each subject. Each subject's voluntary near reading distance and iris color were also recorded. The testing procedures were as follows:

Method 1: Subjective Trial-Lens-Induced Accommodation. The subjects were seated 6 meters in front of a distance acuity chart illuminated by a reading lamp. While wearing the distance correction, the left eye was occluded and the subjects were asked to read the letter chart to determine the smallest letter line that could be read accurately. First, a −0.5 D trial lens was placed in front of the right eye. Subjects were instructed to keep the smallest legible letter line in clear and sharp focus as best they could as increasing negative-power trial lenses were introduced in front of the eye. The subjects responded to the imposed defocus by accommodating. Due to minification of the distant letters by the introduced negative lenses, the subjects were instructed to move up a single letter line if the letters became too small to read. The subjects were asked to indicate when they could no longer clear the letters. The difference between the distance correction and the dioptric power of the last trial lens the subject was able to clear was recorded as the maximum amplitude of accommodation.

Method 2: Subjective Focometer-Induced Accommodation. With the left eye occluded, the subjects viewed the distance acuity chart with their right eye through the focometer, which was mounted on a tripod. The focometer was initially set to the maximum plus power (+10.0 D). The subjects were instructed to slowly turn the focus ring of the focometer to reduce the positive power (increase the negative power) and to stop when they could first clearly read the smallest letter line they had previously read unaided. The dioptric scale of the focometer was recorded to give the spherical power for the distance correction. The subjects were asked to slowly adjust the focus ring from that point in the same direction (toward increasing minus power) until the smallest legible letter line could not be held in sharp focus. Due to increasing minification at higher negative powers, the subjects were instructed to move up 1 line on the letter chart if necessary. The optical power on the focometer was again recorded and the difference in the 2 recorded readings noted. This process was repeated 3 times, and the mean difference between the 2 values was recorded as the subject's accommodative amplitude.

Method 3: Trial-Lens-Stimulated Accommodation Measured with the Hartinger Coincidence Refractometer. The subjects placed their head in a headrest and viewed the distance acuity chart at 6 meters with the left eye. The refraction in the right eye was measured 3 times with the Hartinger. Increasing negative-power trial lenses (−0.5 D, −1.0 D, −2.0 D, etc.) were placed in front of the left eye in a monocle trial-lens holder attached to the headrest to stimulate accommodation. The subjects were asked to read the smallest line on the acuity chart while the consensual accommodative response was measured in the right eye with the Hartinger. A filter that passed the infrared light and cut off the visible light was placed in front of the Hartinger light source to reduce the brightness of the Hartinger mires in the right eye. An infrared-sensitive video camera attached to the eyepiece of the Hartinger was fed to a video monitor to enable the examiner to determine the refraction in the presence of the infrared filter. Three Hartinger measurements were recorded for each trial-lens power. Negative lenses of increasing power were added until no further increase in accommodative response was measured for 3 successively increasing lens powers.

Method 4: Pilocarpine-Stimulated Accommodation Measured with the Hartinger Coincidence Refractometer. Baseline refraction was measured in both eyes with the Hartinger, while the contralateral eye viewed the distance acuity chart. One drop of cyclopentolate hydrochloride 1% (AK-Pentolate) was instilled to cycloplege the left eye, and 1 drop of phenylephrine hydrochloride 2.5% (AK-Dilate) was instilled to pre-dilate but not cycloplege the right eye. After 20 minutes, another baseline refraction was recorded in both dilated eyes. One drop of pilocarpine hydrochloride 6% (Isopto-carpine®) was then instilled in the right eye. Refractions were measured with the Hartinger 3 times in both eyes immediately after the pilocarpine instillation and again at the start of each 5-minute period until 3 successive 5-minute intervals showed no further increase in accommodation. The difference between the baseline refraction and the pilocarpine-induced refraction in the right eye provided the accommodative amplitude.

Results

The best corrected distance visual acuity in the right and left eyes of all subjects was 20/20 or better.

The subjective trial-lens-induced accommodation (method 1) and the subjective focometer-induced accommodation (method 2) showed considerable variability in the amplitude of accommodation measured in this population. In method 1, the mean amplitude was 7.02 D ± 2.00 (SD) (range 3.00 to 11.00 D); in method 2, the mean was 6.83 ± 1.68 D (range 4.00 to 11.00 D). When accommodation was stimulated with trial lenses and measured with the Hartinger (method 3), the mean accommodation was 7.00 ± 0.91 D. When it was stimulated with topically applied pilocarpine and measured with the Hartinger (method 4), the mean amplitude was 5.05 ± 3.05 D (range 2.00 to 10.00 D).

The maximum accommodative responses from the subjective and objective tests were plotted against each other. Figure 1 shows accommodation stimulated with trial lenses and measured objectively with the Hartinger

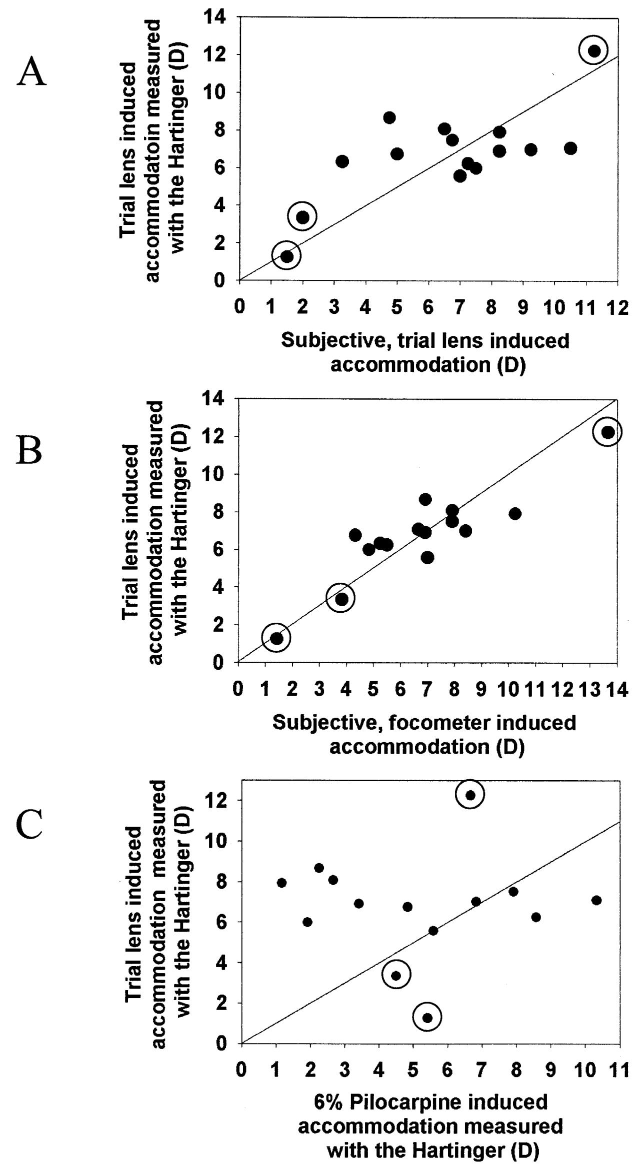

Figure 1. (Wold) Maximum trial-lens-induced amplitudes of accommodation measured objectively with the Hartinger coincidence refractometer plotted against the maximum amplitudes of accommodation measured subjectively with trial lenses (*A*), subjectively with a focometer (*B*), and objectively with the Hartinger when accommodation was stimulated with pilocarpine 6% (*C*). The maximum amplitudes of accommodation measured objectively were similar in all subjects, while the amplitudes measured subjectively varied among subjects. The circled data points represent data from the same 3 subjects.

(method 3) plotted on the *y*-axis and accommodation determined with the other 3 methods plotted on the *x*-axis. Regression lines are not shown because of the variability observed and the small population. The circled points in each graph represent data from the same

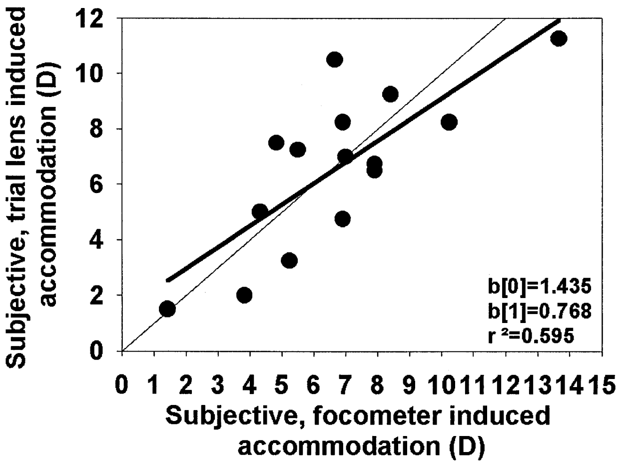

Figure 2. (Wold) The plots of 2 subjective measures of accommodative amplitude. The maximum amplitudes of accommodation measured subjectively are similar as they used similar end-point criteria.

3 subjects, whose objectively measured responses differed from those in the other subjects. The subjective and objective responses in these 3 individuals fall close to the 1:1 line (Figure 1, *A* and *B*). While the objectively measured accommodative amplitude was relatively similar in the remaining subjects, the subjective responses (Figure 1, *A* and *B*) differed considerably. The pilocarpine-stimulated responses also differed considerably among the subjects (Figure 1, *C*). No correlation among the subjective responses and the pilocarpine-induced responses was found. No other significant linear correlations among the methods tested were found.

Figure 2 compares the 2 subjective methods in which accommodation was stimulated with minus lenses and the focometer. The graph shows that subjectively determined accommodative amplitude stimulated with trial lenses or the focometer produced similar responses (slope = 0.768, r^2 = 0.595).

The accommodative response to trial lenses measured with the Hartinger produced similar accommodative responses in this group of subjects, but pilocarpine-stimulated accommodation varied among subjects (Figure 1, *C*). This variability is further evident in Figure 3, in which data from 2 representative subjects are shown. The progressive increase in accommodation with pilocarpine stimulation was similar in both subjects and reached a similar maximum accommodative amplitude (Figure 3, *B* and *D*). However, with increasing trial-lens power, 1 subject (Figure 3, *C*) had a stronger accommodative response than the other (Figure 3, *A*). The subject with the greater pilocarpine-stimulated ac-

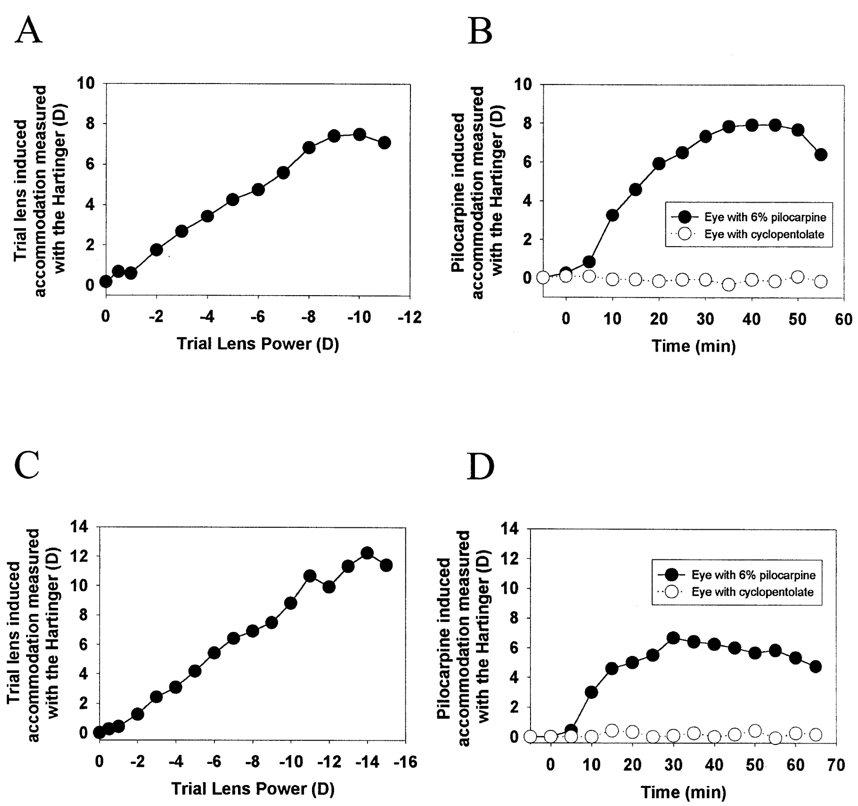

Figure 3. (Wold) Raw data from a subject with a green iris (*A* and *B*) and a subject with a brown iris (*C* and *D*). Each data point is the mean of 3 accommodation measurements with the Hartinger. The responses were similar in the 2 subjects when accommodation was stimulated with topically applied pilocarpine 6% (*B* and *D*), but the amplitudes differed when accommodation was stimulated with trial lenses (*A* and *C*). The open symbols (*B* and *D*) represent measurements in the cyclopleged contralateral eye.

commodation had light irides, while the other subject had dark-brown irides.

Accommodative amplitudes measured objectively with the Hartinger (Figure 4, *A* and *B*) were generally lower when accommodation was stimulated with pilocarpine (Figure 4, *A*) than with negative-power trial lenses (Figure 4, *B*). When stimulated with trial lenses, there was an expected lag in accommodation that increased with increasing trial-lens power (Figure 4, *B*). There was less variability among subjects when accommodation was stimulated with trial lenses (Figure 4, *B*) than with pilocarpine (Figure 4, *A*), as evident from the magnitude of the error bars.

Maximum accommodation stimulated by pilocarpine 6% was generally achieved 33 minutes after instillation (Figure 5, *A* and *B*). When subdivided into groups of light (blue, green, and hazel) and dark (light brown and dark brown) irides, there was a statistically significant difference ($P<.05$) in the maximum response between the 2 groups after 10 minutes (Figure 5, *B*). Subjects with light irides had a stronger accommodative response (mean 8.90 D) than subjects with dark irides (mean 3.53 D). The maximum accommodative response stimulated with pilocarpine in subjects with light irides is similar in magnitude to the maximum trial-lens-induced accommodative amplitude (Figure 4, *B*, and 5, *B*).

The subjects were informally questioned periodically about how they felt after the pilocarpine instillation. Brow ache, mild nausea, and headache were reported to varying degrees. In 1 subject, the experiment was terminated 20 minutes after pilocarpine administration because of ocular discomfort and mild nausea. The subject recovered fully after 30 minutes of rest in a darkened room. Subjects with dark irides reported fewer instances of discomfort and less discomfort.

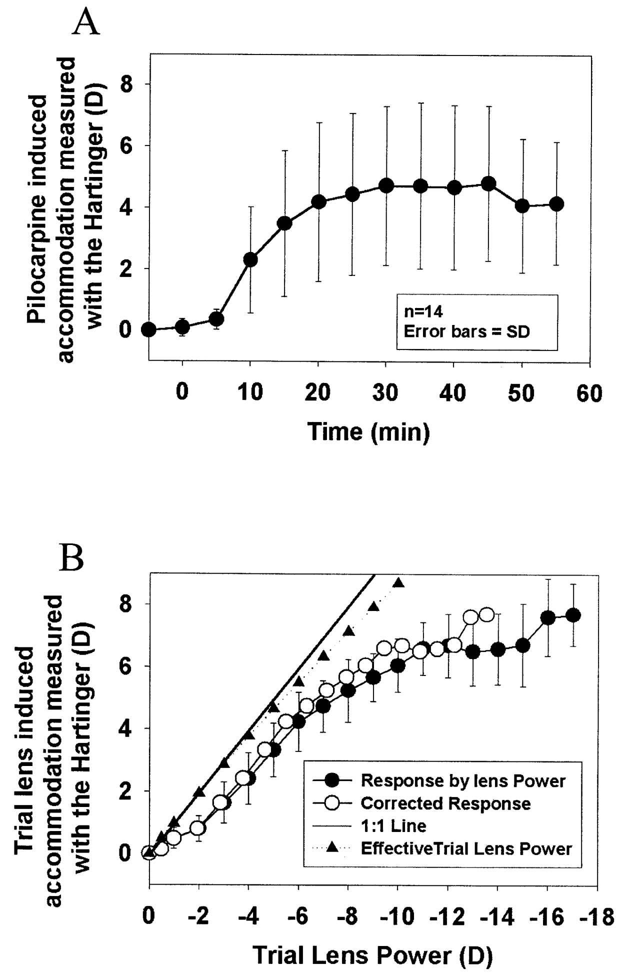

Figure 4. (Wold) *A*: Mean accommodative response to pilocarpine 6% in all subjects followed for 55 minutes with the Hartinger. The error bars illustrate the large variability among subjects. *B*: Mean accommodative responses in all subjects stimulated with trial lenses when accommodation was measured with the Hartinger. The solid lines represent the 1:1 line. Greater amplitude was generally observed when accommodation was stimulated with trial lenses than with topically applied pilocarpine. The trial lenses were placed approximately 12.0 mm from the corneal vertex, so their effective power at the cornea was reduced. Filled triangles represent the calculated effective power of the trial lens at the corneal vertex (*x*-axis) plotted against the actual power inscribed on the lens (*y*-axis). Filled circles are the accommodative response plotted against the power inscribed on each trial lens. Open symbols are the accommodative response plotted against the calculated effective lens power. Error bars show relatively smaller variability among subjects than in *A*.

Discussion

The results in this small group of relatively young subjects varied in subjectively and objectively measured accommodative amplitudes. Although the subject population was small, there were sufficient subjects to demonstrate the efficacy and variability of the methods used. This type of variability is an underreported but not atypical result in laboratory accommodation studies.[34–36] When stimulated by trial-lens-induced blur and measured with the Hartinger refractometer, about 6.0 to 8.0 D of accommodation was measured in most subjects. This is a reasonable and appropriate amplitude for these subjects. Three subjects varied from the norm. Despite being outliers, these amplitudes fall on the 1:1 lines when the objective and subjective results are compared (Figure 1, *A* and *B*). Thus, although the amplitudes were unusual, they were consistent in the 3 methods in which voluntary accommodation was stimulated by induced blur. This suggests this is a true result and represents a clinical variation from the norm in these 3 subjects, 2 of whom accommodated poorly to blur stimulus. In the real world, accommodation is seldom stimulated by blur alone. Normally, proximal, binocular, and convergence cues are present in conjunction with blur. The accommodative response to pilocarpine in these 3 subjects was close to the mean in all subjects. For the 2 subjects with low amplitudes, this suggests that the accommodative physiology or ciliary muscle was functioning normally and the low amplitudes may be due to reduced blur sensitivity.[37]

Apart from the outliers, the most consistent results were obtained when accommodation was stimulated with trial lenses and consensual accommodation was measured objectively with the Hartinger (method 3). This suggests that minus-lens-induced blur can be an effective method to stimulate accommodation in some subjects. Objective measurement ensures that the accommodative response recorded is the actual dioptric change in the power of the eye.

A clear distinction between the subjective and objective methods is shown in Figure 1, *A*, in which accommodation is stimulated in the same way in the 2 cases with negative lenses but measured objectively in 1 case (*y*-axis) and subjectively in the other (*x*-axis). The objective response is consistent across subjects (apart from the outliers), whereas the subjective response varies. In both cases, to measure the maximum accommodative amplitude, the subjects were instructed to clear the smallest line they could to exert the maximum accommodative effort. Although the objectively determined accommodative response lagged behind the lens power (Figure 4, *B*) when measured objectively, the true accommodative response was measured. The lag was due to increasing difficulty overcoming the imposed defocus as lens power increased. The trial lens was placed 12.0 to 15.0 mm in front of the eye, so the effective power of the lens at the corneal plane was less than the actual lens power. A −10.0 D lens placed 12.0 mm from the corneal vertex has an effective power of only −8.9 D at the cornea.

For the purpose of stimulating accommodation, the effectivity of a lens (the lens power determined at some distance from the lens) is unimportant when an objective measurement is made, but it contributes to an overestimation of subjectively measured accommodation when the trial-lens power is recorded as the subject's amplitude. Negative lenses are generally an effective method of stimulating maximum accommodation if an objective measurement is made. When high accommodative amplitudes are stimulated in this way, there is strong convergence and pupil constriction in the eye being measured. Measuring the refraction with the Hartinger became progressively more difficult as the tri-

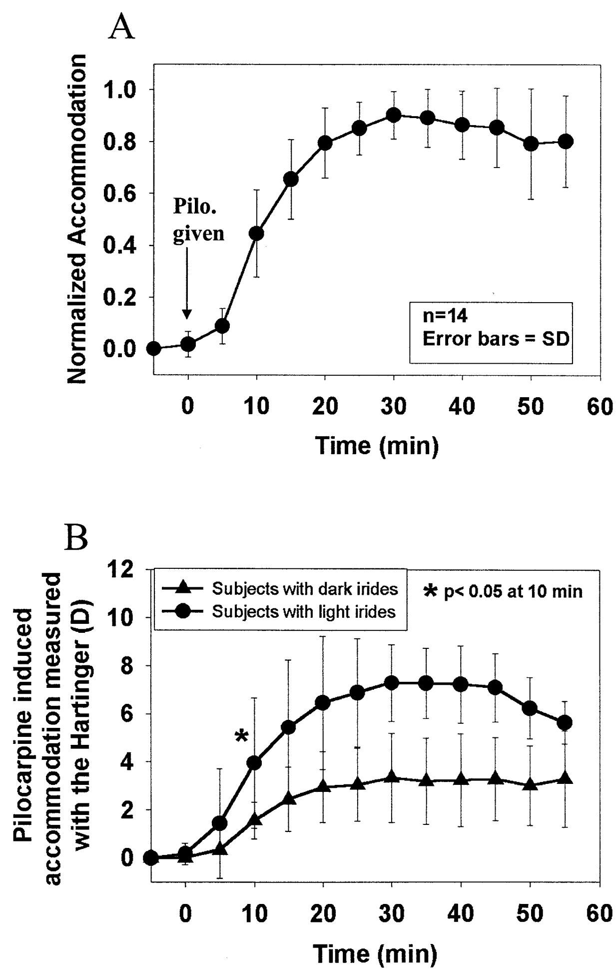

Figure 5. (Wold) When accommodation was stimulated with pilocarpine 6% and measured with the Hartinger, all subjects responded with a similar time course but differed in the amount of accommodation achieved. *A*: The maximal accommodative response of each subject is normalized to 1.0 to better show the time course of the response. In all subjects, maximal accommodation was achieved by about 33 minutes and amplitude began to decline by 55 minutes. *B*: The absolute accommodative responses differed with iris color. Subjects with light irides showed faster and stronger accommodative responses.

al-lens power increased; however, in all cases, measurements could be made.

Other objective optometers or autorefractors fail when pupils become too small. Subsequent testing showed that with a 40 prism diopter eye movement (40 cm at 1 m, approximately 22 degrees), the off-axis refraction measured with the Hartinger differed by about 0.5 D from the on-axis refraction. These measurements, unlike the 2 subjective methods, were of actual dioptric changes in the power of the eye. Depth of focus, pupil size, target size, effectivity, and other factors that could lead to overestimation of subjectively determined accommodative amplitude do not influence the objective measurement.

The trial-lens-induced accommodation tended to be more variable when measured subjectively than when measured objectively. There is no good way to standardize the subjective criteria used to determine when the distance target can not be held in sharp focus. Assessment of accommodation with trial lenses (method 1) and the focometer (method 2) were subject to similar subjective influences. This is evident in Figure 2, which shows a near 1:1 relationship between the 2 methods. Subjective measurements usually overestimate true accommodative amplitude. The mean results with methods 1, 2, and 3 were not significantly different from one another ($P>.05$). The power of statistical tests to detect differences was limited by the small number of subjects and the large interindividual variability observed. Although not statistically different, the objective tests are a measure of optical change in the power of the eye, whereas the subjective tests are not.

Many studies have measured accommodative amplitude subjectively and objectively.[25,38–41] The purpose of the current study was to test methods that have not been systematically studied and could be used for stimulating and measuring true accommodation. We did not use the push-up test, partly because many studies have compared the push-up test with other methods. Rosenfield and coauthors[38] report that the push-up method overestimates the near point measured with dynamic retinoscopy, while Rutstein and coauthors[41] report that dynamic retinoscopy overestimates push-up amplitudes by 2.7 D and the relationship between dynamic retinoscopy and push-up test results vary among examiners. The push-up test requires subjectively determined blur end-point criteria, which may vary considerably among subjects. Accurate dynamic retinoscopy requires considerable examiner skill and subjective evaluation of the extent or direction of movement of the retinoscopic reflex by the examiner. The push-up test and dynamic retinoscopy are routinely used clinically and may be considered reasonable clinical tests to assess accommodation, but they are not accurate objective measures of a dioptric change in the power of the eye.

Topical application of pilocarpine is an objective way of stimulating accommodation in humans because it requires no participation from the subject. Variability in accommodative behaviors is partly due to variability in the ability of subjects to accommodate to various kinds of stimuli. This volitional component to accommodation is eliminated with pilocarpine. Pilocarpine has been advocated as an appropriate way[12] and is widely used[14–23] to stimulate accommodation in humans, but few studies have systematically measured pilocarpine-stimulated refractive changes. The mean accommodative amplitude stimulated with pilocarpine 6% (method 4) was not significantly different from the mean trial-lens-induced accommodation measured objectively (method 3) in this population (t test of the mean, $P = .081$). However, there was no relationship between the results in the 2 tests. The variability and lower overall amplitudes stimulated with pilocarpine were probably the result of different responses to the drug because of iris color. Studies report considerable variability in response to pilocarpine administration but do not mention the effect of iris color.[13,15,23] Subjects with lighter irides are reported to show greater hypotensive response to pilocarpine.[42] Our study showed a significantly greater amplitude in subjects with light irides than in those with dark irides at the 10-minute point ($P<.05$) and all times thereafter.

The efficacy of topical mydriatic agents are influenced by ocular pigmentation. For example, studies[43–45] report differences in the efficacy of different cycloplegic agents and the amount of residual accommodation due to differences in iris color and that cyclopentolate 1% is a more effective cycloplegic agent in subjects with light irides. The results from our study suggest that while topical application of pilocarpine may generally be a relatively poor method of stimulating maximum accommodation, it is an excellent method to objectively demonstrate the presence of accommodation and may be a good approach to compare amplitudes before and after surgical procedures aimed at restoring accommodation in presbyopes. It may also be possible to titrate the dose relative to iris pigmentation to produce the maximum accommodative response in all subjects.

Pilocarpine 6% may be an unusually high concentration relative to a clinical therapeutic dose. Croft et al.[13] used pilocarpine 2% and 6% and report the accommodative response to 6% was greater than that to 2%. We used pilocarpine 6% in a white population to elicit maximum accommodation. In retrospect, the data suggest that this was not a supramaximal dose, particularly in subjects with dark irides. Even higher concentrations may be required in African-American or Hispanic subjects with dark irides to elicit maximum accommodation. On average, the maximum accommodative effect of 1 drop of pilocarpine 6% occurred at about 33 minutes and declined thereafter in subjects with light and dark irides. The measurement end-point criterion was that no further increase in myopic refraction was measured for 3 consecutive 5-minute intervals. A clear decline in accommodation was observed in all but 2 subjects, in whom accommodation was measured up to a maximum 85 minutes after pilocarpine instillation.

Using A-scan ultrasound but not refraction, Abramson and coauthors[15] measured the peak effect to be between 45 and 60 minutes in 20 individuals between 60 years and 80 years of age. The near point measured subjectively 20, 40, 80, and 120 minutes after pilocarpine decreased after 40 minutes and was back to near baseline values by 120 minutes.[23] Croft et al.[13] measured accommodation only at 60 minutes after instillation, which may have been after the maximum effect of the pilocarpine had passed. Abramson and coauthors[15] saw greater increases in lens thickness after prolonged ciliary contraction from the pilocarpine than is possible with voluntary accommodation. Thus, pilocarpine may produce more accommodation than is possible from voluntary accommodation, especially in older subjects or subjects with light irides. This has also been shown to occur with pharmacologically induced accommodation in nonhuman primates.[46]

One drawback of pilocarpine stimulation is rapid and strong pupil constriction. Small pupil diameters make refraction measurements difficult with the Hartinger and often impossible with other instruments that require larger entrance-pupil diameters. This may be particularly true for objective infrared refractometers,[47] clinical autorefractors, or wavefront aberrometers. As with the Canon AutoRef R1 infrared optometer,[47] the Hartinger coincidence refractometer uses a fixed-entrance aperture through which the refraction is measured. As the dilated pupil constricts, the measurements are not affected until the subject's pupil becomes smaller than the fixed-entrance pupil aperture required by the optometer. In our study, phenylephrine 2.5% was used to pre-dilate the iris to slow pupil constriction and prolong the period over which refraction could be measured. Despite the pronounced pilocarpine-induced pupil constriction, no measurements were terminated because the pupil diameters became too small. The Hartinger coincidence refractometer is 1 of a few objective refractometers capable of measuring refraction through 1.0 to 2.0 mm pupils.

Gimpel and coauthors[48] measured the effects of phenylephrine 2.5% on accommodative amplitude using the subjective push-up technique and report a net decrease of 1.22 D in the accommodative amplitude after 30 minutes. However, the decrease in accommodative amplitude measured using the subjective push-up technique may be a result of a decreased depth of focus due to the dilated pupils rather than a diminution of the true accommodative amplitude. Objective assessment of the accommodative amplitude after phenylephrine would be a more appropriate method to ascertain whether and how much phenylephrine reduces accommodation. Given the profound pupil constriction produced with pilocarpine, it is unlikely that pre-dilation with phenylephrine substantially, if at all, reduces the pilocarpine-stimulated accommodative amplitude.

The subjective push-up test, routinely used to measure accommodative amplitude, may be adequate for most clinical applications, but it is inadequate for demonstrating true accommodative amplitude, ie, the change in the optical power of the eye, and it cannot be used to suggest that surgical procedures can restore accommodation in presbyopes. Subjective tests typically overestimate true accommodative amplitude and at best can serve only as an estimate of near reading ability. Near reading ability is clinically important for patient satisfaction, but it is not an appropriate measure of true accommodation. The 2 objective methods used in this study, although resulting in variability among individuals and with differences among techniques, unequivocally stimulate and measure accommodation. The challenges associated with objective accommodation measurement, the variability observed, and the clinical acceptability of subjective testing do not justify the use of subjective tests in scleral-expansion patients.

Further tests have been undertaken on a larger population of prepresbyopic and presbyopic subjects with low accommodative amplitudes including testing retest reliability to assess the efficacy of using these methods in the target population for which surgical procedures are claimed to be effective at restoring accommodation (L. Ostrin, A. Glasser, Opt and Vis Sci abstract 105, 2001). With the current study, we intended to develop baseline data in normal young subjects against which the results in normal older subjects can be compared. The normal older subjects will represent a control population against which patients who have had accommodation-restoration procedures can be compared (L.A. Ostrin, S. Kasthururangan, A. Glaser, Opt and Vis Sci abstract 79, 2002). While a control population is useful for testing the accommodation measurement methodology, the credibility of scleral-expansion procedures that claim to restore accommodation in presbyopes can be established only by objective tests performed preoperatively and postoperatively.

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