Article ▸ Comparison of Three Methods of Measuring CA/C Ratios

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ABSTRACT

Background: Clinical determination of convergence accommodation to convergence (CA/C) ratios may be useful for analysis of accommodation and vergence disorders, but there are no standard clinical methods of measurement of CA/C ratios. This study compared two potential clinical CA/C measurement methods to a laboratory procedure.

Methods: CA/C ratios were measured for 19 young adult subjects using procedures in which accommodation was measured with the binocular cross cylinder (BCC) test, Nott dynamic retinoscopy, and an eccentric photorefractor. Vergence was stimulated with prism, and the resultant change in accommodation was used to calculate CA/C ratios.

Results: The mean CA/C ratios were 0.036 D/Δ with BCC and BI prism, -0.004 D/Δ with BCC and BO prism, 0.023 D/Δ with Nott retinoscopy and BI prism, 0.036 D/Δ with Nott retinoscopy and BO prism, and 0.115 D/Δ with eccentric photorefraction and BO prism. The differences between each pair of tests were statistically significant by paired t-test except for the comparison of the BCC BI prism CA/C ratio with the Nott BI prism CA/C ratio. The means and standard deviations of the paired differences were all high relative to the measurements themselves.

Conclusion: The CA/C ratios obtained in the present study did not show good agreement with each other. The use of CA/C ratios in clinical analysis would therefore require further evaluation and standardization of measurement methods, establishment of norms, and development of analysis procedures in concert with AC/A ratios and other clinical findings.

Keywords: binocular cross cylinder test, binocular vision disorders, convergence accommodation, dynamic retinoscopy

Introduction

Accuracy of vergence and accommodation are affected by many factors, among them being accommodative convergence and convergence accommodation. The potential contributions of these two factors can be quantified by accommodative convergence to accommodation (AC/A) ratios and convergence accommodation to convergence (CA/C) ratios.

To determine AC/A ratios, it is necessary to eliminate the stimuli to fusional vergence so that the effect of accommodation on vergence can be observed. This is easily done clinically with dissociated phoria testing. To determine CA/C ratios, it is necessary to eliminate the effect of blur cues to accommodation so that the effect of vergence on accommodation can be observed. At present, there is no standard method for routine clinical measurement of CA/C ratios.

Several investigators have suggested that the measurement of both AC/A ratios and

CA/C ratios could enhance clinical diagnosis of accommodation and vergence disorders.[1-5] Two methods of clinical determination of CA/C ratios have been proposed.[1] Both of them involve measurement of accommodation with varying convergence stimulus levels resulting from use of prism. One method incorporates dynamic retinoscopy measurements while the patient views a target that gives minimal indication of the level of blur. One such target is a Difference of Gaussian pattern, which has a blurred light bar with blurred dark bars on either side of it.[3] A second clinical test used in the evaluation of accommodation that has been suggested for measurement of CA/C ratios is the binocular cross cylinder (BCC) test, which yields the dioptric level at which accommodative stimulus and accommodative response are equal.

For AC/A ratios, a distinction is made between stimulus AC/A ratios and response AC/A ratios, with accommodative stimulus being in the denominator of the former and accommodative response being in the denominator of the latter. Because lag of accommodation can represent a significant percentage of the accommodative stimulus, there can sometimes be sizable differences between stimulus and response AC/A ratios. In contrast, fixation disparity, measured in minutes of arc, represents a small percentage of the convergence stimulus measured in prism diopters. (For example, ten minutes of arc, which is a fairly large amount of fixation disparity, would be equivalent to less than a third of one prism diopter.) This makes convergence stimulus and convergence response close to the same, and as a consequence, a distinction is not usually made between stimulus and response CA/C ratios.

With either dynamic retinoscopy or the BCC test, the CA/C ratio can be calculated as the difference in accommodation between prism and no prism conditions divided by the power of the prism. CA/C ratios can also be calculated as the slope of a linear regression of accommodation as a function of prism power if several prism powers are used.

The results of studies that have reported CA/C ratios are summarized in Table 1. There are a number of laboratory studies that have used an optometer or autorefractor to measure accommodation.[6-12] Mean CA/C ratios in those laboratory studies have ranged from 0.055 D/Δ to 0.14 D/Δ. Mean CA/C ratios in three studies using dynamic retinoscopy and the BCC test have ranged from 0.045 D/Δ to 0.087 D/Δ.[1,3,13]

There have been three previous studies that have compared clinical and laboratory methods of measuring CA/C ratios. Schor and Narayan[1] reported CA/C ratios for five subjects with three different methods of measuring accommodation: BCC, Nott retinoscopy, and a coincidence optometer in a half-silvered mirror haploscope. Accommodation for a 40 cm test distance was measured with no prism and with 6^{Δ} base-in prism. The change in accommodation was divided by the change in dissociated phoria from no prism to 6^{Δ} base-in prism. Dissociated phorias were taken right after each test of accommodation. They chose to use phorias in the denominator in that study rather than the amount of prism because they wanted to eliminate a potential effect of prism adaptation that may have been induced by fusional vergence stimulated by the prism. Prism adaptation may reduce the size of the dissociated phoria, thereby decreasing the fusional demand. For this reason, the phoria, rather than the amount of prism, was thought to provide a better estimate of the fusional demand. Each test was performed five times on each subject, and the mean of each set of five repetitions was used in the analysis. The mean CA/C ratios for the five subjects were 0.087 D/Δ (SD=0.032) using the BCC test, 0.08 D/Δ (SD=0.025) using Nott dynamic retinoscopy, and 0.075 D/Δ (SD=0.025) with the coincidence optometer. The coefficients of correlation of BCC CA/C ratios with optometer CA/C ratios

Table 1: Mean CA/C ratios in D/Δ from previous studies. Standard deviations are in parentheses. Separate columns indicate the procedure by which accommodation was measured.

Study	BCC	MEM or Nott dynamic retinoscopy	Optometer
Kent (n=17)			0.13 (0.06)
Hung et al. (22 asymptomatic subjects)			0.12 (0.05)
Hung et al. (21 symptomatic subjects)			0.11 (0.05)
Rosenfield & Gilmartin (n=30)			0.06
Kotulak et al. (n=16)			0.10 (0.08)
Nonaka et al. (78 subjects with exophoria or exotropia)			0.08 (0.04)
Brautaset & Jennings (10 subjects with convergence insufficiency)			0.14 (0.02)
Fukushima et al. (n=16)			0.09 (0.04)
Schor& Narayan (n=5)*	0.087 (0.032)	Nott: 0.08 (0.025)	0.075 (0.025)
Tsuetaki & Schor (n=6)		Nott: 0.045 (0.022)	0.055 (0.021)
Daum et al. (78 asymptomatic subjects)		MEM: 0.06 (0.05)	
Daum et al. (22 symptomatic subjects)		MEM: 0.07 (0.06)	
Wick & Currie (Nott, n=40; optometer, n=11)		Nott: Median about 0.035	Median about 0.04

**In the Schor and Narayan study, there were CA/C ratios with BCC and Nott retinoscopy but not with optometer for a sixth subject. With all six subjects, the mean CA/C ratios were 0.107 D/Δ (SD=0.057) with BCC and 0.09 D/Δ (SD=0.032) with Nott retinoscopy.*

and of Nott retinoscopy CA/C ratios with optometer CA/C ratios were both high (r=0.9). (A sixth subject in their study had BCC and Nott CA/C ratios reported, but no optometer CA/C ratio. With that subject, the mean CA/C ratios were 0.107 D/Δ with BCC and 0.09 D/Δ with Nott retinoscopy.)

Tsuetaki and Schor[13] measured CA/C ratios for six subjects using Nott retinoscopy and an infrared optometer. Accommodation measurements were taken with no prism and with twelve different prism powers while subjects viewed a Difference of Gaussian target. CA/C ratios using Nott retinoscopy and the optometer were calculated by determining the slope of a linear regression of accommodative response as a function of prism power. The optometer used in the study was a modified Bausch & Lomb Ophthalmetron that measured reflected light from the ocular fundus via a half-silvered mirror. Vergence was stimulated with various amounts of prism and measured with an infrared eye movement monitor. The mean CA/C ratio using Nott dynamic retinoscopy was 0.045 D/Δ (SD=0.022). The mean CA/C ratio using the optometer arrangement was 0.055 D/Δ (SD=0.021). Measures were highly correlated across subjects (r = 0.92).

Wick and Currie[14] measured CA/C ratios using Nott retinoscopy performed on 40 subjects. Accommodation was measured while subjects viewed a Difference of Gaussian pattern through 3, 6, 9, and 12^{Δ} prisms, both base-in and base-out. The CA/C ratio was calculated using linear regression. They did not report an average CA/C ratio, but based on a graph in their paper, the CA/C ratios ranged from close to zero to about 0.06 D/Δ, with a median of about 0.035 D/Δ. They also tested eleven subjects with both their Nott retinoscopy procedure and an optometer in a haploscopic arrangement. They did not report means for those eleven subjects either, but a scatterplot of the results shows that the range of CA/C ratios was 0.02 to 0.08 D/Δ with both methods. The correlation between Nott retinoscopy CA/C ratio and optometer CA/C ratio was high (r=0.79).

In those three studies, the calculation of the CA/C ratio with BCC or dynamic retinoscopy was determined using many repetitions of each test or many different prism powers. While this may enhance accuracy and precision of measurements, such approaches are unlikely to be incorporated into the daily patient care routine of a busy practitioner. Perhaps a reasonable expectation of the busy clinician would be to obtain two accommodation measurements with no prism and two accommodation measurements with one prism power. That is the approach that we chose to adopt in the present study for the BCC and dynamic retinoscopy procedures.

The purpose of the present study was to compare CA/C ratio measurements collected with three different methods of measuring accommodation: (1) BCC test, (2) Nott dynamic retinoscopy, and (3) a laboratory video-based eccentric photorefractor.

Subjects

Nineteen subjects volunteered to participate in this study. Subjects were contacted through an email that informed them of the purpose of the study, their expected role, and the potential time commitment. The procedures used in this study were approved by the Indiana University Institutional Review Board.

Subjects were required to wear their habitual optical correction: either no refractive correction or contact lenses. Exclusion criteria were best-corrected distance visual acuity less than 20/20 in either eye, strabismus at distance or near as determined by cover test, or previous refractive surgery. Otherwise, there were no inclusion or exclusion criteria related to binocular vision status. Subjects were instructed to avoid sustained near work for at least 30 minutes prior to data collection.

Subjects ranged from 23 to 30 years of age at last birthday, with a mean age of 25.8 years. Ten of the nineteen subjects were optometry students. Nine of the subjects did not wear refractive correction. Spherical subjective refractions of the subjects (over-refractions for the contact lens wearers) yielded a range of -0.25 to +0.50 D for both right and left eyes.

Methods

Three methods of determining CA/C ratios were compared. Convergence was stimulated with prism in each of the three procedures. The three methods differed in the techniques used for the measurement of accommodation: (1) the clinical BCC test, (2) clinical Nott dynamic retinoscopy, and (3) a laboratory procedure using eccentric photorefraction (PowerRefractor, MultiChannel Systems). One of the four authors did all of the clinical testing, and another did all of the laboratory testing. For eleven subjects, the clinical procedures were done before the laboratory testing, and for eight subjects, the laboratory procedure was performed first, as determined by the experimenters' schedules. When the data were examined for subjects separated by whether clinical testing was done first or laboratory testing was done first, the results were very similar, so data are reported in this paper in the aggregate. For the two clinical methods, the BCC test procedure was done before Nott dynamic retinoscopy on odd-numbered subjects, and Nott retinoscopy before BCC on even-numbered subjects.

BCC Testing

For the clinical tests, interpupillary distance was measured with a PD rule. An American Optical phoropter was set for the near interpupillary distance. A standard BCC cross grid card was placed on the phoropter reading rod 40 cm from the spectacle plane. The phoropter auxiliary lens dials were turned to the cross cylinders. The stand light rheostat was turned down as in standard BCC testing. The lenses in the phoropter were set at +1.75 D over each eye. Subjects were asked whether the horizontal or vertical lines were blacker and more distinct. If the expected (vertical) was not obtained, more plus was added until the vertical lines were more distinct. Subjects were instructed to report when the two sets of lines were equally distinct or the horizontal lines were more distinct before plus power was reduced binocularly. When an equal response was obtained, the amount of lens power in the phoropter was recorded. If the subject gave a horizontal response without an equal response, the 0.12 D step between the last vertical response and the first horizontal response was recorded.

The BCC test determines the amount of plus power (or minus power if a lead of accommodation is present) required to make accommodative stimulus and accommodative response equal. With BI prism, decreased convergence accommodation would decrease the accommodative response, and thus more plus would be expected on the BCC test. With BO prism, increased convergence accommodation would increase the accommodative response, and thus less plus would be expected on the BCC test.

The BCC test was performed twice with no prism, then twice with 8^{Δ} BI, and lastly twice with 8^{Δ} BO. It was decided to use equal powers in the BI and BO direction, with the choice of the prism powers being somewhat arbitrary. It was decided to use as high a power as most persons would be able to fuse, a higher power being desirable because resultant changes in accommodation would be more likely to be observed. The prism was split equally between the two eyes using the phoropter rotary prisms. The mean of the two measurements in the presence of the prism and the mean with no prism were used for the determination of CA/C ratios for each subject. A BI CA/C ratio and a BO CA/C ratio were calculated for each subject with the formula:

CA/C = (mean BCC with no prism –
mean BCC with prism) / prism power

where BI prism was negative and BO prism was positive, so CA/C ratios would be expected to be positive numbers.

Nott Dynamic Retinoscopy

Nott dynamic retinoscopy was performed with an American Optical phoropter set at the near interpupillary distance. Lens powers in the phoropter were set at zero. Subjects viewed a Difference of Gaussian target (a target with a light stripe in between two black stripes lacking distinct edges) on the reverse side of a Wesson Fixation Disparity Card (Figure 1) at a distance of 40 cm from the spectacle plane. Subjects were instructed to look at the white stripe just below the hole in the card. No verbal response was required. The stand light was turned off during testing, and overhead lighting was dim. The Difference of Gaussian target and low light level opened the accommodative loop by minimizing the cues available to accommodation. The examiner started the Nott retinoscopy procedure with the retinoscope just behind the plane of the test card, and if a "with" motion was observed, the examiner moved back until a neutral motion was observed. The examiner noted the distance of the retinoscope from the spectacle plane when neutral was observed and used the reciprocal of that distance in meters to obtain an accommodative response measurement.

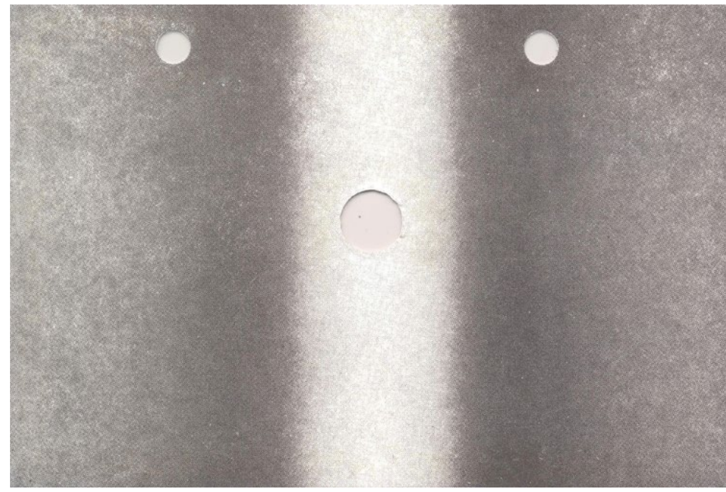

Figure 1: Difference of Gaussian target used for Nott retinoscopy *The retinoscope light was directed through the hole in the middle of the card. The two holes at the top of the card were used to suspend the card from the phoropter reading rod.*

Nott retinoscopy was performed on the right eye twice with no prism, then twice with 8^{Δ} BI, and lastly twice with 8^{Δ} BO. The prism was placed over the left eye using the phoropter rotary prisms. The mean accommodative response (AR) for the two measurements with the prism and the mean with no prism were used for the determination of each CA/C ratio for each subject. A BI CA/C ratio and a BO CA/C ratio were calculated for each subject with the formula:

CA/C = (mean AR with prism – mean AR with no prism) / prism power

where BI prism was negative and BO prism was positive.

Laboratory Procedure using Eccentric Photorefraction

Accommodative and vergence responses were measured simultaneously using the PowerRefractor (PR) (Multi Channel Systems), a commercial eccentric photorefractor and Purkinje image eye tracking technology.[15,16] The PR collects data from a viewing distance of one meter at a video frame rate of 25Hz. Light from a set of near infrared (IR) LEDs located beneath the PR camera aperture passes into each eye and reflects back from the retina through the pupil. The dioptric focus of each eye in the vertical meridian is derived from the slope of a linear regression fit to the distribution of reflected light across the pupil. Vergence responses are obtained using the relative displacement of the first Purkinje image with respect to the image of the pupil center in each eye.

The PR uses a population-average defocus calibration based on data collected from adults.[15,17] Similarly, a population-average Hirschberg ratio is used to calculate gaze position and vergence.[15] Individual defocus and eye position calibrations were performed on all participants in order to calculate the relative changes in accommodation and vergence.[18] A relative calibration is performed by occluding vision in one eye with a near infrared filter (while data are still collected from the eye) and placing a sequence of lenses and prisms of different powers over that filter.[19] The calibration factor for defocus was determined by introducing five lenses (+1, 2, 3, 4, -2 D) in front of the occluded eye and deriving the slope of the linear function relating induced anisometropia in the PR readings to lens power. Similarly, an estimate of the slope of the vergence position function was determined by optically shifting the Purkinje image of the occluded eye using base-out prisms (4, 8, 12, 16$^{\Delta}$). The occluded eye does not compensate for the lens or prism, and thus the effect of the lens or prism can be compared relative to the other, uncovered eye. When the prism was inserted over one eye, a version response was also required for fusion, due to the asymmetric vergence demand. The analyses were performed solely on the difference in horizontal gaze position between the alignment at one stimulus distance and the alignment at the other stimulus distance. Thus the version trajectories taken by the eyes during the movement from one distance to another did not impact the analyses of the final alignment.

Participants watched a high contrast cartoon movie with naturalistic spatial frequency amplitude spectra displayed on an LCD screen. The LCD screen was held at a constant viewing distance of 90 cm during the calibration but was moved to 40 cm during CA/C testing. The image from the LCD screen was reflected from a beam splitter to reach the subject in order to prevent the LCD screen from blocking the optical path of the photorefractor. The participant was carefully aligned so that the visual target and the PR camera were centered on the midline between their eyes. During CA/C measurements, a blurred version of the movie was shown (blur open-loop). Blur cues were removed by inserting a low-pass spatial filter with a Difference of Gaussian (DOG) printed on it in front of the LCD screen. This DOG target was printed on a spatially low-pass material. In addition, a 2 D luminance Gaussian was used to make the periphery of the target dark and therefore to reduce contrast at the edge of the screen. Informally, this DOG filter and the DOG target used for Nott retinoscopy appeared equivalent for opening the accommodative loop for blur, but this was not quantified formally.

The LCD screen with the blurred movie was held at a constant viewing distance of 40 cm while an 8^{Δ} base-out prism was introduced before the right eye. The participant viewed the target binocularly. The prism was held in front of the eye for 8 to 10 seconds and then removed for approximately 8 to 10 seconds. This procedure was repeated for a total of 7 to 9 repetitions. Base out was used because it is easier for most individuals to converge than to diverge. Only one prism base direction was also used because the accommodation measurements were essentially instantaneous with a change in fusional vergence, so that differential effects of vergence adaptation to base-in and base-out prism would not be a factor.

Raw accommodation and vergence data were filtered before analyzing the CA/C ratios. Individual points were excluded using the following criteria: (1) accommodation fell outside the linear range of the instrument (+4 D to -6 D), (2) pupil size was <3mm or >8mm, or (3) eye position was greater than 15 deg from alignment with the camera. The remaining data for inclusion were smoothed using a 240-ms averaging window. Data analyses were performed using MacSHAPA, Matlab, and Microsoft Excel software. Video of each experimental session was recorded and analyzed offline using MacSHAPA to determine the frames when a lens or prism was introduced and removed. These marked frames formed a stimulus profile and were used as a reference when analyzing accommodation and vergence responses.

Defocus and eye alignment in the calibration condition were estimated by averaging 2 seconds of steady-state data (50 data points) before and after each lens and prism was introduced. The measured changes in focus and vergence were plotted as a function of lens and prism power, respectively. The slopes of the functions were determined using linear regression, and the individuals' raw data were then corrected for their calibration factor.

Similar to the calibration condition, accommodative and vergence responses in the CA/C condition were measured by averaging 2 seconds of steady-state data before and after the introduction of the 8^{Δ} base-out prism (with the prism introduced 7 to 9 times in that condition). The measured change in accommodation and vergence for each stimulus change (i.e., with and without prism) was plotted in Excel. Responses for a particular stimulus change were excluded if there were poor reflections (preventing data acquisition) or the change in vergence was less than 0.5 meter angles. There were typically between 3 and 9 (mean 6.3) repetitions included in calculation of the CA/C ratios. Accommodative and vergence responses for each stimulus change were averaged to obtain an overall mean accommodation and vergence response for each subject. Each subject's CA/C ratio was determined by dividing the overall mean (convergence-induced) accommodative response by the overall mean vergence response.

In the PowerRefractor, the estimate of the eye's defocus is derived from the distribution of reflected light in the video image of the pupil.[19-21] In the analysis approach used, 2 seconds of data were averaged at each stimulus distance, and the estimate of the accommodation response was derived from the difference between these averages. An estimate of the sensitivity of this approach can be determined using a classical sample size or power calculation for a t-test of the difference in means. The typical standard deviation of the measurement over 2 seconds is 0.2 D.[18] For a power of 80% and a p value of 0.05, this analysis approach is able to detect a 0.08 D difference in the means with 50 samples (the 2 second averaging window).

Table 2: CA/C ratios (in D/Δ) with each testing procedure in the present study

Subject	BCC method BI prism	BCC method BO prism	Nott method BI prism	Nott method BO prism	Lab method BO prism
1	-0.01	-0.03	0.02	0.04	0.15
2	0.04	-0.02	0.01	0.07	0.17
3	0.04	0.05	0.02	0.04	0.15
4	0	-0.02	0.04	0.02	0.23
5	0.04	-0.04	-0.01	ND	0.09
6	-0.06	0.09	0.04	0.01	0.10
7	0.04	0.02	0.02	0.06	0.11
8	0.03	-0.07	0.04	0.05	ND
9	0.13	-0.05	0.01	0.02	0.08
10	0.07	-0.09	0.02	0.05	0.13
11	0.02	0.01	0.01	0.04	0.15
12	0.06	-0.01	0.03	0.03	0.11
13	0.03	-0.01	0.02	0.07	0.12
14	0.08	0.05	0.02	0.03	0.12
15	0.01	0.01	0.02	0.02	0.06
16	0.06	0	0.01	0.03	0.03
17	0.05	0.03	0.03	0.01	0.11
18	0.08	0	0.06	0.03	0.06
19	-0.03	0	0.01	0.03	0.09
N	19	19	19	18	18
Mean	0.036	-0.004	0.023	0.036	0.115
Std. deviation	0.043	0.043	0.016	0.019	0.047
Median	0.04	0	0.02	0.03	0.11
Minimum	-0.06	-0.09	-0.01	0.01	0.03
Maximum	0.13	0.09	0.06	0.07	0.23

ND = not determined

Statistical Analysis

Comparison of the results for the different testing methods was done with ANOVA and paired t-tests and by finding the means and standard deviations of the individual differences between the CA/C ratios from each pair of testing methods. Altman and Bland[22] have also noted that the evaluation of agreement of clinical measures should examine whether the difference between two tests is dependent on the magnitude of the measurements. This was assessed by taking subject means from each pair of methods and determining Pearson correlation coefficients between the differences between two measurement methods and the means of those two methods. A Bonferroni correction for the 13 statistical significance tests done resulted in a p level of 0.0038 for statistical significance (0.05 divided by 13).

Results

Individual and mean CA/C ratios with each testing procedure are presented in Table 2. A CA/C ratio was not determined for one subject using the Nott procedure with BO prism because this subject shifted from a small lag of accommodation with no prism to a lead of accommodation with BO prism, and the accommodative response is difficult to measure with Nott retinoscopy when there is a lead. A CA/C ratio was not determined for one subject with the laboratory procedure because that subject did not respond to the prism during the laboratory testing procedure.

Table 3: Results of paired t-tests

Comparison	Paired t-test
CA/C with BCC BI prism & CA/C with Nott BI prism	t=1.248; p=0.228
CA/C with BCC BO prism & CA/C with Nott BO prism	t=3.073; p=0.0069
CA/C with BCC BI prism & CA/C with Lab method	t=4.683; p=0.0002
CA/C with BCC BO prism & CA/C with Lab method	t=7.371; p<0.0001
CA/C with Nott BI prism & CA/C with Lab method	t=8.061; p<0.0001
CA/C with Nott BO prism & CA/C with Lab method	t=7.194; p<0.0001

With the formulas used for CA/C calculation in this study, CA/C ratios would be expected to be positive because a decrease in accommodation would be expected with BI prism and an increase in accommodation would be expected with BO prism. Negative CA/C ratios were found for some subjects with the BCC and Nott retinoscopy methods, particularly when using BO prism with the BCC procedure. This is likely due to measurement noise when CA/C ratios were very close to zero.

With the exception of BCC with BO prism, the mean and median CA/C ratios with the BCC and Nott retinoscopy were around 0.02 to 0.04 D/Δ. The mean and median CA/C ratios for the laboratory method were just over 0.1 D/Δ.

A significant difference in CA/C ratios between the five conditions was found with ANOVA (F=27.49; p<0.0001). Post-hoc paired t-tests are given in Table 3. The differences were statistically significant (p<0.0038 with Bonferroni correction) for all four comparisons of the laboratory CA/C ratios with BCC and Nott CA/C ratios.

BCC and Nott CA/C ratios were not significantly different by paired t-test with Bonferroni correction, but Bland and Altman plots[23] (Figures 2 and 3) suggest that the difference between the two methods increases with magnitude of measurements, implying poor agreement. This is confirmed by the statistically significant correlations of differences between methods with the means of the two methods (Table 4). For comparisons of Nott CA/C ratios with the laboratory CA/C ratios, correlations of differences between methods with the means of the two methods were also statistically significant (Table 4), again suggesting poor agreement.

Table 4: Mean and standard deviation of the differences between methods and the correlations of the individual differences with means (*p<0.01).

Difference in CA/C ratios	N	Mean	Standard deviation	Correlations, differences, & means (r)
BCC CA/C with BI prism minus Nott CA/C with BI prism	19	0.013	0.046	0.76*
BCC CA/C with BO prism minus Nott CA/C with BO prism	18	-0.039	0.054	0.70*
Lab CA/C minus BCC CA/C with BI prism	18	0.079	0.071	0.07
Lab CA/C minus BCC CA/C with BO prism	18	0.115	0.066	0.12
Lab CA/C minus Nott CA/C with BI prism	18	0.093	0.049	0.80*
Lab CA/C minus Nott CA/C with BO prism	17	0.081	0.046	0.73*

The means and standard deviations of the differences between measurements (Table 4) are all high relative to the measurements themselves, indicating poor agreement for all comparisons.

Discussion

The results from the present study show poor agreement between methods for determining CA/C ratios. There was a particularly large difference between the laboratory and clinical testing procedures. The mean CA/C ratio for the laboratory procedure in the present study was over 0.1 D/Δ. Many of the previous studies summarized in Table 1 also had CA/C ratios over 0.1 D/Δ using a laboratory procedure. The clinical procedures in the present study yielded mean CA/C ratios well below 0.1 D/Δ, and previous studies generally reported CA/C ratios below 0.1 D/Δ using clinical procedures. One of the possible weaknesses of CA/C ratios as a potential diagnostic tool is that they are typically small numbers.

The laboratory procedure used in the present study yielded response CA/C ratios,

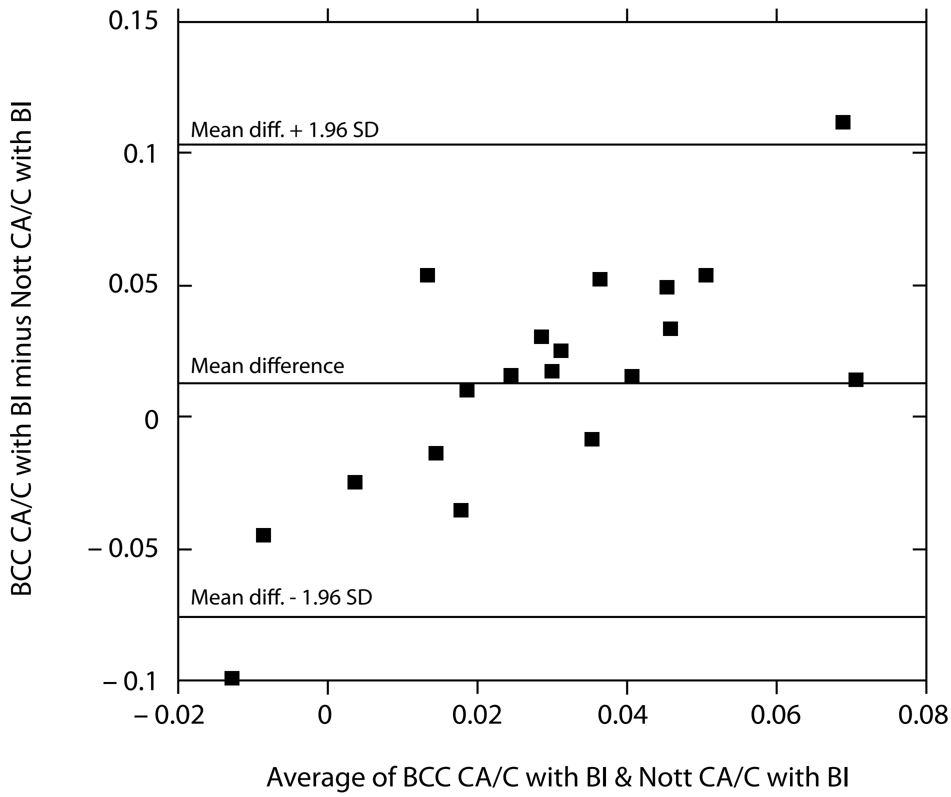

Figure 2: Bland-Altman plot for comparison of clinical CA/C ratios with BI prism *The apparent good fit of the data by a straight line suggests that the difference between measurements varies as a function of their magnitude, suggesting poor agreement.*

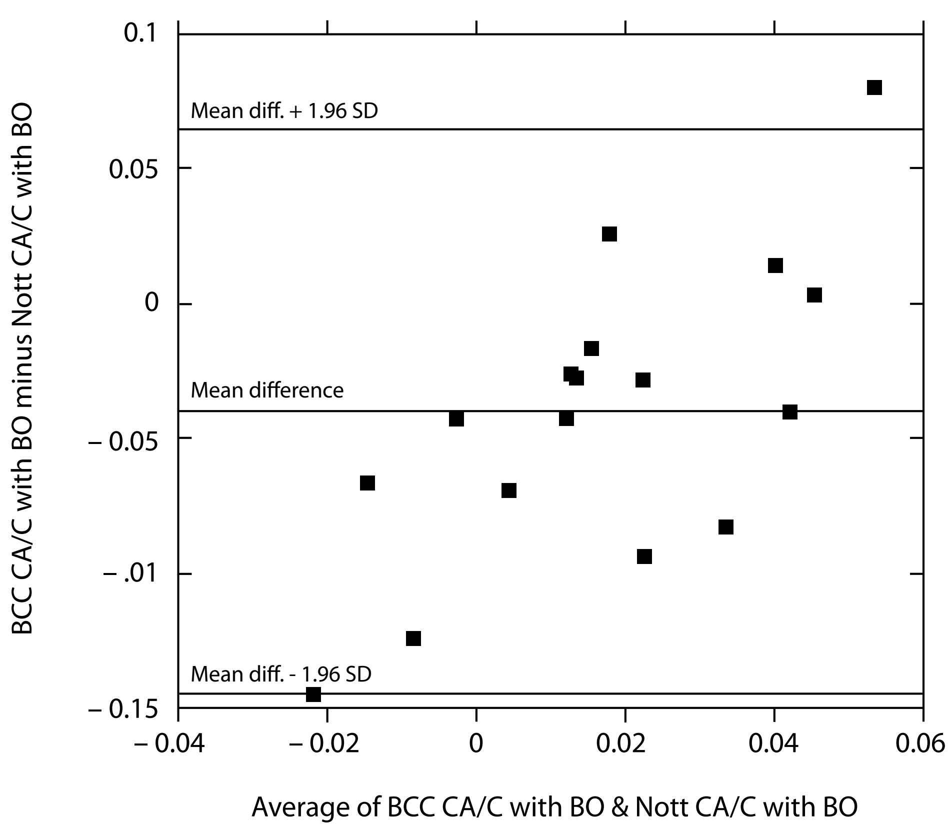

Figure 3: Bland-Altman plot for comparison of clinical CA/C ratios with BO prism *The apparent good fit of the data by a straight line suggests that the difference between measurements varies as a function of their magnitude, suggesting poor agreement.*

that is, CA/C ratios in which the change in accommodative response was divided by the change in vergence response. The clinical procedures yielded stimulus CA/C ratios, where the CA/C ratio was determined using change in accommodative response divided by change in vergence stimulus. However, because a vergence response is typically close to the vergence stimulus, there should be relatively little difference between response and stimulus CA/C ratios, unlike the difference that often exists between response and stimulus AC/A ratios.

A potential explanation for the difference in the results using laboratory and clinical procedures may come from the time course of the measurements during the procedures. The laboratory method used in the present study yielded an accommodative measurement that was essentially instantaneous with the vergence response to the prism. In contrast, with the clinical methods, the subject viewed through the prisms for several seconds before the procedure was completed, allowing vergence adaptation (prism adaptation) to occur. Vergence adaptation may replace some of the effort of fusional vergence.[2] Because it is thought that fusional vergence drives convergence accommodation, the amount of convergence accommodation may decrease as vergence adaptation increases.[2] As the time between the insertion of the prism and the measurement of accommodation increases, fusional vergence and convergence accommodation would be increasingly replaced by vergence adaptation. The similarity between clinical and optometer measures of CA/C found in previous studies[1,13,14] suggests that there could have been time during which vergence adaptation may have occurred in both clinical and laboratory procedures, in contrast to the laboratory CA/C procedure in the present study.

It is unclear which type of CA/C measurement could possibly be of more value in the diagnosis of binocular vision disorders. It could be argued that the measurement of CA/C prior to vergence adaptation may be intrinsically more informative because it describes the initial effect of fusional vergence on accommodation, in which case some variation of the laboratory procedure used here may be more useful. However, because vergence adaptation aids in reducing strain on fusional vergence and is occurring during everyday seeing, it could also be argued that allowing vergence adaptation to occur would permit measurement of a CA/C ratio that is more clinically useful, in which case a procedure like the clinical procedures used here may be more useful.

Daum et al.[3] suggested that the negative CA/C ratios that they obtained on some subjects with MEM retinoscopy were due to measurement errors. Another possible explanation for negative CA/C ratios is adaptation in that convergence accommodation would not occur if vergence adaptation replaced fusional vergence, allowing random variability to result in some negative CA/C ratios. In the present study, there were several subjects with negative CA/C ratios on the BCC procedure with BO prism, suggesting that the BCC with BO prism may not be a promising method for determining CA/C ratios. Some subjects reported that it was difficult to maintain fusion of the BCC cross grid target with prism in place.

Conclusion

The CA/C ratios obtained in the present study with BCC and Nott retinoscopy clinical procedures and with an eccentric photorefraction laboratory procedure did not show good agreement with each other. The clinical test results in the present study were largely similar to previous clinical test results, and the laboratory test results were largely similar to previous laboratory technique results. Theory suggests that clinical determination of CA/C ratios could enhance diagnostic analysis, but the incorporation of CA/C ratios in clinical analysis would require further evaluation and standardization of measurement methods, establishment of norms, and development of analysis procedures in concert with AC/A ratios and other clinical findings.

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