Original Article

Estimation Dynamic Distance Direct Ophthalmoscopy (eDDDO): A novel, objective method for the quantitative assessment of accommodation in young children

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Purpose: To describe estimation dynamic distance direct ophthalmoscopy (eDDDO) and compare it with the monocular estimation method of dynamic retinoscopy (eDR) for the assessment of accommodation in children. **Methods:** In this prospective observational cohort study, an ophthalmologist performed eDDDO followed by eDR in children with normal eyes, and then under the partial effects of cyclopentolate and tropicamide to assess performance of eDDDO with eDR under the condition of pharmacologically induced accommodation failure. Only one eye of each child was recruited in the study. To study the inter-observer variation, two masked pediatric ophthalmology fellows performed eDDDO in the similar manner. **Results:** For the comparison of eDDDO with eDR, 60 eyes of 60 patients were recruited. The mean age of the patients was 10.4 years. The mean accommodation on eDDDO was 3.0D, 5.1D, 9.8D, and 11.3D at 40 cm, 25 cm, 10 cm, and 8 cm, respectively and 3.0D, 5.0D, 9.5D, and 11.0D on eDR. The eDDDO overestimated accommodation by a mean 0.17D (95% CL 0-0.48D, $P = 0.5$). The correlation of eDDDO with eDR was excellent (Pearson r 0.98, T value 76.0). The inter-observer difference with eDDDO was not significant (mean 1D, 95% CL 0-2.6D, $P = 0.9$) and the correlation between two observers was excellent (Pearson r 0.9, T value 12.7). The eDDDO and eDR were also performed on 12 eyes of 6 children with a mean age of 8.5 years (range 8-12 years) under the partial effect of cyclopentolate and tropicamide, where eDDDO overestimated the accommodation by a mean 0.3D (95% CL 0- 1.2D, $P = 0.7$) and the correlation was excellent (Pearson r 1.0, T value 45). **Conclusion:** eDDDO is a simple, reliable, quantitative, and objective technique of accommodation assessment for children. Further studies with larger sample are required to assess its performance in disorders of accommodation affecting younger children and in children with ocular comorbidities.

Key words: Accommodation, aniso-accommodation, dynamic distance direct ophthalmoscopy, dynamic retinoscopy, monocular estimation method, ophthalmoscopy, photorefraction, retinoscopy

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Accommodation is the process by which the refractive power of an eye is altered to focus on objects at varied distances and create a clear retinal image.[1] In humans, this change naturally occurs through the following mechanisms: (1) an increase in the optical power of the crystalline lens through a decrease in lens diameter, (2) an increase in lens axial thickness, and (3) an increase in curvature of the anterior and posterior surfaces of the lens.

For any individual, accommodation is a crucial element of vision that warrants clinical assessment during regular check-up. The current gold standard for the clinical evaluation of accommodation in young children is dynamic retinoscopy.[2,3] Dynamic retinoscopy (DR) requires a patient to continuously fixate and resolve an accommodative target for an extended period of time, while the examiner subjectively neutralizes the reflex from the subject's retina using lens, a process which can take time and be fairly difficult. The examiner has to perform the retinoscopy back and forth from one eye to the other in order to detect aniso-accommodation (difference in accommodative response between the two eyes). In addition, at times an inadvertent off-axis DR reveals scissoring and confusing reflexes.[2]

On the other hand, a novel method named dynamic distance direct ophthalmoscopy (DDDO)[4] was recently reported to be a simple, objective and reliable technique, based on the principle of photorefraction, that uniquely allows examiners to assess accommodation from both eyes simultaneously. Although DDDO was originally described for the qualitative evaluation of accommodation in young children, DDDO can be employed for the quantitative assessment of accommodative dysfunction through simply applying the principles of estimation methods of DR [Fig. 1]. The range of responses in estimation DR (eDR)

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is from “with” motion to neutralization to “against” motion, eDDDO is more akin to non-eccentric photorefraction, where a series of plus or minus spherical lenses are briefly placed in front of the eye and the range of reflexes assessed using a direct ophthalmoscope as they move from a crescent above or below [Fig. 2] to a crescent in the opposite direction.

The purpose of this study was to evaluate eDDDO against eDR, the current gold standard method for assessing accommodation, both of which employ supplementary lenses. We report that eDDDO is a reliable, simple, fast, and easy to perform test with its distinct ability to be performed on both eyes simultaneously.

Methods

This prospective observational study was performed in the department of pediatric ophthalmology at Mahatme eye hospital and eye bank, Nagpur and Jyotirmay eye clinic, Thane. The study protocol was cleared by the institutional ethics committee. The subjects were recruited after obtaining informed oral consent from their parents. The oral consent included an explanation of the examination techniques, confidentiality, and truthful reporting of the data for scientific use. The study had four components: (1) recording the technique of eDDDO for photographic documentation, (2) comparison of eDDDO with eDR, (3) evaluation of interobserver variations of eDDDO, (4) comparison of eDDDO with eDR under pharmacologically induced variable cycloplegia and mydriasis that allowed for a complete assessment of the technique when employed for accommodation failures or pupillary dysfunction.

For the first part of the study we included a child <16 years who had normal eyes.

eDDDO was performed on the right eye (RE) of the child using a direct ophthalmoscope (Heine, Beta 200, Optotechniq, Germany). The room lights were switched off to create semi-dark condition. The subject was asked to look with both eyes at a 20/200 optotype on a Snellen chart kept at a distance of 20 ft. The author (MK) peered through the ophthalmoscope held at a distance of 40 cm in the left hand and recorded the transpupillary reflex using a handycam held in the right hand (Panasonic, SDR-H95, USA). The refractive error of the examiner was fully corrected and the lens dial of the ophthalmoscope head was kept at zero. The ophthalmoscope was held close to the line of sight of the patient and a large aperture size with full illumination was used for the assessment.

A retinoscopy rack with lenses in steps of + 0.25D (xxx) was used to neutralize the bright transpupillary light crescent located superiorly. First, a + 0.5D lens was interjected in front of the subject’s eye and removed; the interjection was quick (<1 second) to avoid instigating accommodation. The power of the lens was increased until the superior transpupillary bright crescent disappeared and a bright, inferior crescent appeared [Fig. 3].

The subject was then asked to read the N8 line on the near vision chart held at 40 cm while the observer neutralized the transpupillary light reflex [Fig. 4]. When the patient shifted from 40 cm to 25 cm, the reflex had already shifted inferiorly due to the pseudomyopia induced with accommodation, which then required a progressively higher minus lens to neutralize the inferior crescent. Neutralization is defined as the point just beyond the dead zone (no superior or inferior crescent), where one observes the first appearance of the superior crescent and the complete disappearance of the inferior crescent. When neutralizing at distance (20 ft.), we begin with plus lenses, which induce myopia and reduce power until this point is obtained; in the case of near, we begin with briefly adding minus lenses, which induce hyperopia, and increase power until the same endpoint is achieved. We recognize that in a single measurement there may be an over/underestimation of accommodation due to observational uncertainty in the neutralization point, but the difference between two measurements of accommodation (at two distances, e.g., 40 cm and 25 cm) is valid because the same endpoint is used, and thus the constant over/underestimation in each of the two measurements is ultimately negated when the two values are subtracted. As a result, any point can technically be used as the endpoint when making these measurements.

The accommodation exerted for a given distance (A in diopters) was defined as

A = power of neutralizing convex lens needed for distant fixation (20ft) – power of neutralizing lens needed for near fixation (40, 25, 20, 10, 8 cm) (Formula 1). For the subject mentioned in Figs. 1-4, who is essentially emmetropic, the neutralizing lens required for the distance fixation was + 1.5D and that for the near fixation at 40 cm was -0.5D and -3.5D at 25 cm. Hence the accommodation exerted (response accommodation) at 40 cm = +1.5- (-0.5) = 2.0D and that at 25 cm = +1.5D- (-3.5) =5.0D.

It is relevant to mention here that a well-recognized problem that the addition of minus-powered lenses will induce transient accommodation which causes an overestimation of the power required to neutralize the accommodation reflex, and thus, in the comparison of the Monocular Estimation Method (MEM) and Nott, two DR techniques, MEM was said to be inferior.[5] This is a limitation of the eDDDO as well (as it is based on MEM). However, the Nott technique can be more difficult and time consuming particularly due to the difficulty in maintaining a precise distance from the observer (if set), and otherwise, in measuring the distance between the retinoscopy and the observer once the point of neutralization is found (especially for children).[5] As a result, MEM is often preferred.[5,6] There is a strong correlation between the results of MEM and Nott (correlation coefficient is r = 0.90) and so the Nott accommodation value can be easily calculated from the MEM result by simply dividing by 2.[5] It is certainly possible, though, that the DDDO technique is adapted to use photorefraction as done in the Nott method, but this would require further studies to compare it against the MEM-based technique. We have chosen to compare two MEM-based techniques (requiring the addition of supplementary lenses) for this study. We also recognize that the lens can only be placed in front of the eye for a brief period of time, due to the issue with transient accommodation aforementioned. In our experience, performing photoretinoscopy using a retinoscope takes slightly longer than performing photorefraction with a DO, and this slight amount can be significant in the case of neurological reflexes. Hence, we chose to employ the DO.

In the second component of the study, children aged 6-16 years with normal eyes were recruited in the study to obtain the normative data for response accommodation at

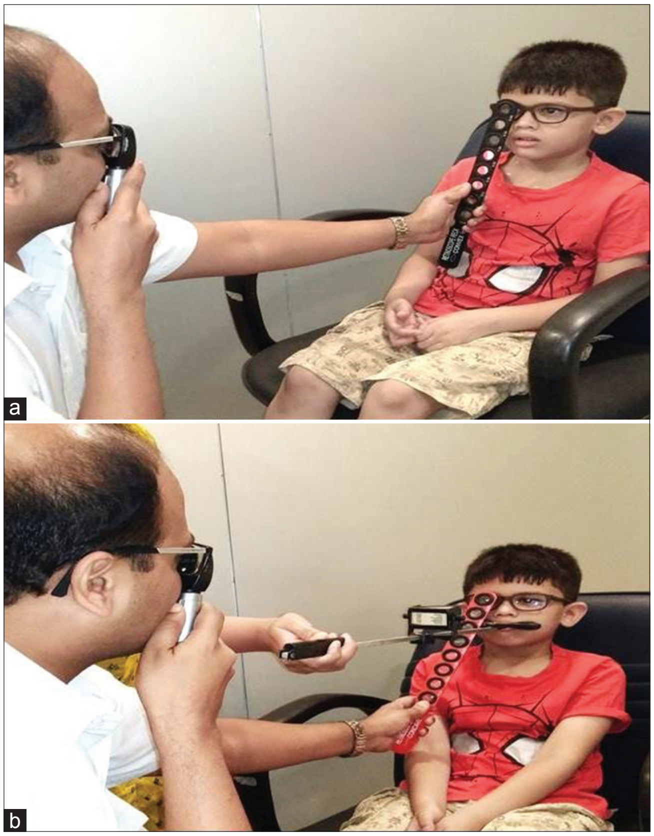

Figure 1: Clinical photographs demonstrating the technique of estimation dynamic distance direct ophthalmoscopy (eDDDO). (a) An examiner peers through a direct ophthalmoscope visualizing the transpupillary light reflex while the child is reading from a vision chart placed at far distance. A plus lens from the lens rack (black) is interjected to neutralize the superior crescent. (b) Child is reading from the near vision chart placed at 40 cm distance and the examiner neutralises the inferior crescent visualised from transpupillary light reflex by introducing a minus lens from the lens rack

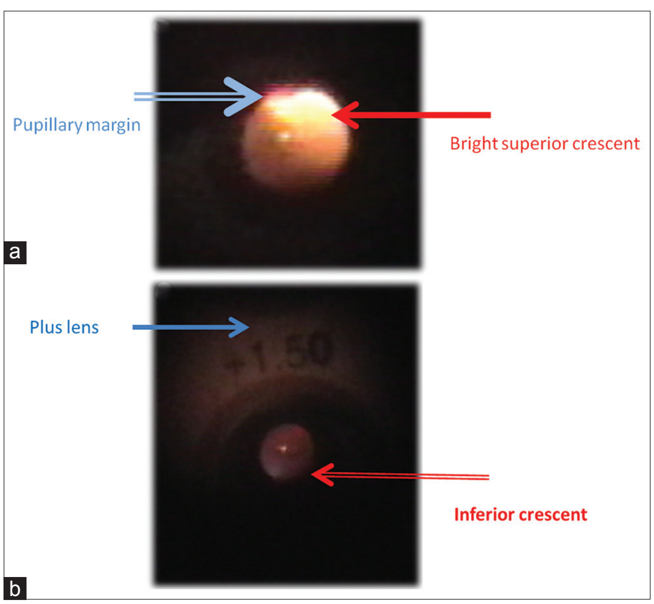

Figure 3: Photograph demonstrating the neutralization of the transpupillary light reflex using eDDDO. (a) Superior bright crescent is visualised when an emmetropic child was fixating at a distance of 20 ft. (b) Note the disappearance of the superior crescent and appearance of early inferior crescent with the +1.5D lens

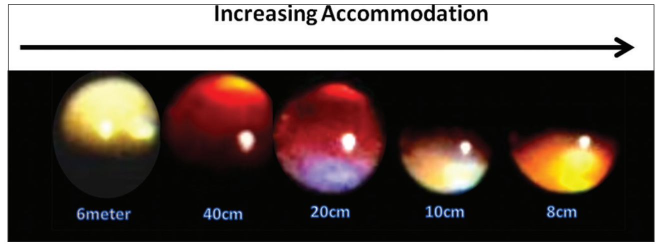

Figure 2: A clinical photograph showing a collage of five transpupillary light reflex captured on eDDDO that demonstrate disappearance of a superior bright crescent when the eye is not 'accommodated' and increasing size of the inferior bright crescent as the accommodation is progressively increased when the point of fixation receded from 6 ft. to 8 cm

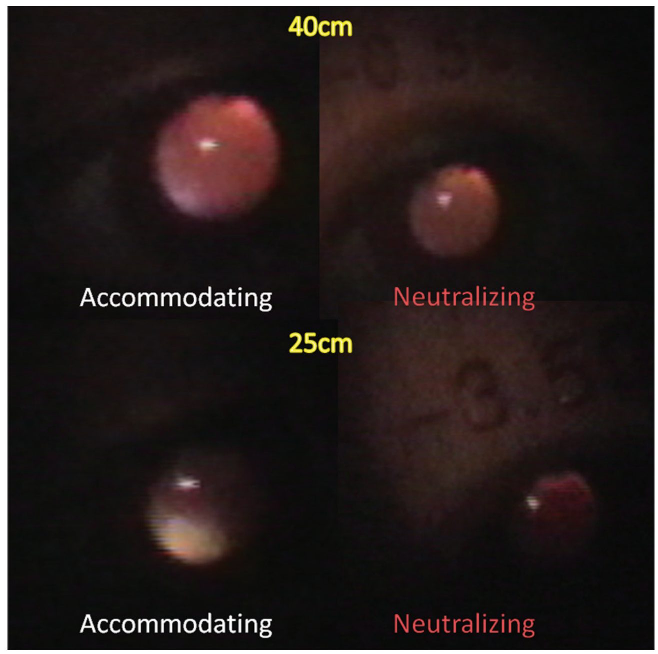

Figure 4: Transpupillary light reflex on eDDDO when the child is accommodating while fixing at 40 cm and 25 cm and the inferior crescent being neutralized with -0.5D and -3.5D respectively

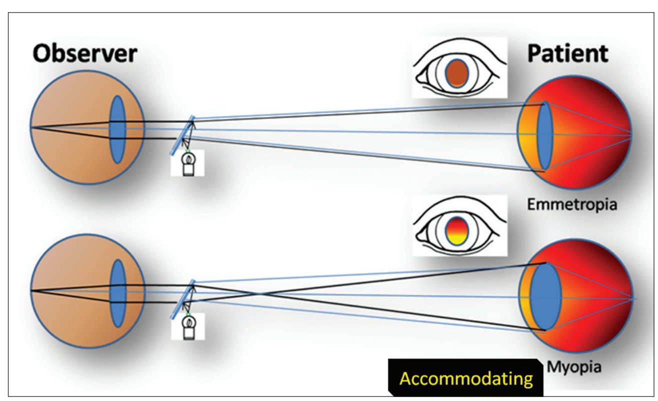

Figure 5: Diagram demonstrating the optics of DDDO. A superior bright crescent is formed when the eye is fixated for distance and an inferior crescent is formed when the eye is fixated for the near

40 cm, 25 cm, 10 cm, and 8 cm using the eDDDO and compare it with eDR. The MEM, as described previously, was used for eDR.[5]

The child was asked to fixate at a distant object (Snellen 20/200 optotype at a distance of 20 ft.) in a semi-dark room. The senior author (unmasked to the finding of eDDDO) held the streak retinoscope (Heine, Beta 200, Optotechniq, Germany) and neutralized the transpupillary crescent, with movement using plus-powered spherical lenses in the horizontal meridian (streak vertical). This was followed by neutralization of the pupillary light reflex for near as the child fixated and read N8 line at 40 cm, 25 cm, 10 cm, and 8 cm in steps. It was ensured that the reflex was observed from the center of the pupil rather than from the edge. Clinically, it is of no importance to check accommodation in multiple meridians. The only advantage that a retinoscope offers over DO is the ability to check meridional accommodation, which may be of importance in patients with coloboma.[7]

It is important to note that in both the techniques, it is critical that the lens be interjected quickly, the reflex evaluated, and the lens removed quickly. Prolonged exposure (>1 second) to the lens induces an accommodative response and result in inaccurate and invalid data.

The neutralization on eDR is defined as the lens that caused a reversal of the direction of the movement of the streak of light on retinoscopy. eDR was performed only in horizontal meridian.

The values from eDDDO and eDR were entered into a Microsoft Excel sheet for statistical analysis.

Only one eye of every subject was included for the study.

Sample Size Calculation:[8]

The formula used for the calculation of the sample size was appropriate for a continuous variable for the paired data.

We used the formula - $n = (Z_{1-\alpha/2} - Z_{1-\beta/2})^2 Sc^2/d^2$

$Z_{1-\alpha/2} =$ level of significance = 1%=2.58

$Z_{1-\beta/2}$ = power of the study = 90% = -1.28

Sc = standard deviation = 0.5D

d = effect size = 0.25D

Putting this value in above formula

$n = (2.58 - (-1.28))^2 (0.5)^2/(0.25)^2$

$= (3.96)^2 \times 0.25/0.625$

$= 14.8996 \times 4$

= 59.596

= 60

In the third aspect of the study, inter-observer variation was studied. eDDDO was performed on one eye of 10 consecutive children by two masked equally experienced senior pediatric ophthalmology fellows using the same accommodative target in the same lighting condition one after the another in a single session with an interval of 1 minute.

In the fourth aspect of the study, eDDDO and eDR were performed under the partial effects of cyclopentolate and tropicamide.

We included 12 eyes of 6 subjects who had to undergo cycloplegic refraction for their ophthalmic evaluation, though all of them had normal eyes. The nursing staff was instructed to instill cyclopentolate 1% eye drops in one eye and tropicamide 1% in the other eye in a randomized manner. The author (XX) was masked to the information regarding which eye had received which drug. Thirty minutes later, eDDDO and eDR were performed for both the eyes. The results were recorded to assess the validity of eDDDO under variable cycloplegia and semi-mydriatic condition.

Inclusion criteria:
1. Children aged 6–16 years
2. Uncorrected visual acuity of 20/20
3. Cooperative for complete examination
4. Parental oral consent for recruitment in the study.

Exclusion criteria:
1. Neurologically impaired child/hyperactive child
2. Coexisting ocular diseases
3. History of eye injury
4. Patients taking antihistaminics (H1 blockers), serotonin antagonist

(5 HT or oral anticholinergics)

Two tailed, paired *t* test for samples with equal variance was used as a test of significance.

Correlation coefficient (Pearson r) and 95% confidence intervals were calculated for the statistical analysis. T value (statistical significance of Pearson correlation coefficient) was calculated for the given sample size.

Results

The results in Tables 1 and 2 are of the difference between the accommodation measured at near and distance, as previously described. Thus, given that the same point is used for neutralization, there is not any over/underestimation in the data mentioned and thus the results are valid.

Comparison of eDDDO with eDR:

Totally, 60 eyes of 60 patients were recruited. The mean age of the patients is 10.4 years (standard deviation 2.3, range 7–14 years), and the gender distribution is 37 males and 25 females.

The eDDDO overestimated the accommodation by mean 0.17D (range 0.0D–0.3D, **95% CL 0–0.48D)**. This difference between the accommodation measured on eDDDO and eDR was statistically insignificant (*P* = 0.5, Table 1). The correlation between eDDDO and eDR was excellent (Pearson r 1.0, T value 75.9 for all the measurements considered together). Nevertheless, eDDDO tends to overestimate the accommodation as the target moved closer to the subject, due to the off-axis drifting of the eyes from the observer and the increase in size of the dead zone which in turn increases variability. It was qualitatively observed during the study that eDR became more difficult to perform as the object approached 10 and 8 cm, compared to eDDDO, due to the difficulty in assessing the neutralization of light reflex on retinoscopy up-close.

Table 1: Comparison of eDDDO with eDR in normal eyes without effect of cycloplegia

Fixation distance (in cm)	Response accommodation eDDDO (in Diopters) Mean [95% Confidence Limits (CL)]	Response accommodation eDR (in Diopters) Mean (95% CL)	Statistical Tests (*n*=60)		
			P (paired *t* test)	Pearson *r* (Correlation coefficient)	*t* of Pearson *r*
40	3.0 (2.4-3.6)	3.0 (2.4-3.5)	0.9	0.92	18.2
25	5.1 (4.2-6)	5.0 (4.1-6)	0.8	0.93	19.6
10	9.8 (8.7-10.9)	9.5 (8.1-10.8)	0.5	0.96	26.6
8	11.3 (10.2-12.5)	11.0 (10-12.1)	0.6	0.98	38.1

Table 2: Comparison of eDDDO with eDR under partial cycloplegia and mydriasis

12 eyes, 6 children, 48 measurements	eDDDO (*n*=48)	eDR (*n*=48)
Mean response accommodation in diopters	6.62	6.33
95% Confidence Limit	0.15-13.1	0.12-12.6
P (Paired *t* test)	0.7	
Pearson Correlation Coefficient (*r*)	1.0	
t of *r*	45	

Table 3: Inter-observer variation in eDDDO between two pediatric ophthalmology fellows

10 eyes, 10 children, 40 measurements	Observer 1	Observer 2
Mean response accommodation in diopters (SD)	5.2 (3.0)	5.1 (2.7)
Mean difference (95% Confidence Interval)	**1D, (0-2.6D)**	
P (Paired *t* test)	0.9	
Pearson Correlation Coefficient (*r*)	0.9	
t of *r*	12.7	

Inter-observer variation:

It was observed that there is a learning curve associated with the technique, and there can be some inter-observer variation. We included 10 eyes of 10 children and found that the inter-observer difference ranged from 0.1D to 1.1D (**95% CL 0-2.6D,** *P* = 0.63, correlation coefficient r = 0.64). The difference was least at 40 cm [Table 3].

The performance of eDDDO with eDR under partial cycloplegia and mydriasis:

Total ten eyes of five patients were included. Mean age of the children was 9.8 years (standard deviation 2, range 8–12 years). Gender distribution was 1 male and 4 females. Under variable and partial cycloplegia, eDDDO was not much different from eDR and correlated well (*P* = 0.7, Pearson r = 1.0, T value 12.5). There was no significant difference in the performance of both the tests irrespective of distance and whether the cycloplegic agent was tropicamide or cyclopentolate (n = 5).

Due to small sample size [Tables 2 and 3] further analysis of data at 40 cm, 25 cm, 10 cm, and 8 cm was not undertaken.

Discussion

In this study we have described a novel application of DDDO, eDDDO, and compared it with eDR for the clinical assessment of accommodation in young children. This study was done to compare two clinical techniques. Both are subjective and utilized the same "lens insertion" technique. Response accommodation measured by eDDDO was comparable to that measured on eDR and the correlation was between the two techniques was excellent.

eDDDO was observed to be easier to perform at close fixation distances (i.e. 10 and 8 cm) compared to eDR. Using an openfield autorefractor or photoscreener is warranted for future studies where this subjective technique would be compared with an objective technique.

The eDDDO overestimated the accommodation by mean 0.17D. The probable reason for these differences lie in the fact that eDDDO follows the principles of photorefraction. Photorefraction involves the use of a still image, addition of the lens, and observation of the pupil, while retinoscopy requires movement (to produce the moving shadow), on top of addition the lens and observation of the pupil. Thus, photorefraction is a simpler process. When the light rays from a direct ophthalmoscope are reflected back from an emmetropic eye, they form a superior crescent due to divergence of the reflected light rays in front of the ophthalmoscope [Fig. 5]. As subject accommodates, the refractive status of the eye changes from emmetropic (diverging rays) to pseudomyopic (converging rays), making the reflected light rays emerge in more convergence causing the disappearance of superior crescent and appearance of an inferior bright transpupillary crescent.[4]

We found that the neutralization of the crescents on eDDDO was easier than neutralization of the light reflex on eDR, especially for closer fixation distance. It is important to note, however, spherical aberration, astigmatism, and irregular astigmatism can make it difficult to perceive the crescents when the pupils are dilated using DDDO.[4] In addition, there is an increase in the dead zone when the size of the pupil is constricted.[4] eDR may be more accurate in patients with media opacity, irregular cornea, and high astigmatism than eDDDO. Future studies are needed before eDDDO is used in such situations.

The correlation between eDDDO and eDR is high, and both the techniques were equally effective under cycloplegia and mydriasis.[5] Overall reproducibility of eDDDO (inter-observer difference) was similar to eDR (0.9D with eDDDO in this study versus 0.8D with eDR by León AÁ *et al*.[9]). However, it needs to be reassessed in future studies with masked observer, larger sample, and in younger children with various ocular comorbidities.

A possible limitation of eDDDO and eDR is that children are often anxious of objects near their faces, and hence this technique may be limited in applicability to older children, though the use of free lenses could help to employ this technique on younger children. Further studies with larger sample are required to better assess the inter‑observer agreement and the performance of eDDDO in various disorders of accommodation affecting young children. The greatest limitation of this technique, like eDR, is that this method relies on the brief introduction of minus trial lenses for neutralizing the respective type of reflex while the patient is continuing to focus on a near target. It is possible that accommodation is significantly stimulated even with such brief introductions. While the latency in human accommodation in response to adding minus powered lenses is about 400 ms, it is possible that the accommodation reflex happens even faster due to an automatic reflex when an object suddenly comes that close to the patient's face. In this way, it is not necessarily to the lens that the patient is accommodating, but simply to the near distance of an object. In order to avoid this issue, eDDDO can easily be adapted to the Nott technique and further investigated. Although it might provide more accurate results, it may be challenging to measure distances when working with children.

Conclusion

In summary, eDDDO is a simple, quantitative, reliable, and objective technique of assessing accommodation in children. The eDDDO was found to be a faster technique, but the greatest advantage that eDDDO distinctly presents, is that allows for the simultaneous assessment of both eyes. While technically it is also possible to perform eDR binocularly by holding the streak in a horizontal position and moving away far enough to illuminate both eyes simultaneously, eDR is difficult to perform, especially for those with shorter arms, as the distance can be too much for placing lenses in front of the patient's eye for measuring accommodation. Further studies are required to rigorously and quantitatively compare both the techniques in these regards.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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