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Association between crystalline lens thickness and intermittent exotropia in children: a cross-sectional observational clinical study

Jingxin Li[1†], Xiangxiang Liu[1†], Jie Hao[1], Fengchao Zhou[1], Huixin Li[1], Yiyang Zhao[1], Yumeng Wang[1], Lei Li[1] and Jing Fu[1*]

Abstract

Purpose To investigate the relationship between crystalline lens thickness (LT) and subtypes of intermittent exotropia (IXT) in children, focusing on ocular biometry and accommodation characteristics.

Methods This cross-sectional study included 501 children aged from 8 to 12 years: 122 with orthophoria (Group A) and 379 with IXT, which were further categorized into basic type (Group B, $n=254$), convergence insufficiency (CI) type (Group C, $n=92$), and divergence excess (DE) type (Group D, $n=33$). Evaluation of strabismus was measured after diagnostic occlusion. Cycloplegic refraction and assessments of accommodation and convergence functions were performed. All children were examined with Lenstar LS-900 with fixation at non-accommodative target monocularly and ocular biometric parameters including axial length (AL), mean keratometry (Km), central corneal thickness (CCT), LT and aqueous depth (AD) were recorded. Regression analyses were performed to evaluate associations among groups.

Results The basic type was the most prevalent IXT subtype (67.0%), followed by CI (24.3%) and DE (8.7%). The CI group exhibited greater binocular LT ($P=.002$) and lower accommodative convergence-to-accommodation (AC/A) ratio compared to the basic type ($P=0.016$). Compared to orthophoric controls, the basic IXT group showed greater accommodative amplitude (AMP) ($P=0.004$), reduced accommodation lag ($P=0.006$), and more distant near point of convergence (NPC) ($P<0.001$). Both univariate and multivariate logistic regression analyses indicated that the CI IXT was associated with greater LT ($P=0.006$) and lower AC/A ratio ($P=0.007$) compared to basic IXT. Basic IXT was correlated with greater AMP ($P<0.001$), reduced lag of accommodation ($P=0.002$) and more distant NPC ($P=0.003$) compared to controls.

Conclusions Increased LT and lower AC/A ratio were significantly associated with the CI subtype of IXT in children. The basic type is characterized by greater AMP, reduced accommodation lag, and more distant NPC compared to orthophoric controls. These findings could serve as valuable clinical markers for managing IXT, and contribute to a deeper understanding of the pathophysiology of types of IXT.

Keywords Intermittent exotropia, Convergence insufficiency, Lens thickness, Accommodation

† Jingxin Li and Xiangxiang Liu contributed equally to this work.

*Correspondence:
Jing Fu
fu_jing@126.com

Background

Intermittent exotropia (IXT) is the most common type of childhood-onset exotropia, characterized by an outward deviation of one eye, typically when viewing distance objects [1–3]. The reported prevalence of IXT in Asian children, which showed an increasing trend over the past few decades [4], ranged from 0.12 to 3.90% [3, 5–7]. IXT is generally classified into three types: basic type, convergence insufficiency (CI) type and divergence excess (DE) type, basing on the degree of exodeviation observed at different viewing distances using diagnostic occlusion, as defined by Duane [8] and Burian [9]. A tailored treatment approach was required for different subtypes of IXT to address their unique binocular vision characteristics.

Previous studies have highlighted an association between ocular deviation and binocular functions related to accommodation and convergence, especially in cases of comitant esotropia. Accommodative esotropia has been attributed to uncorrected hyperopia, which increases accommodative demand and, consequently, accommodative convergence [10]. Additionally, acute acquired comitant esotropia (AACE) is characterized by a high accommodative convergence-to- accommodation (AC/A) ratio and low accommodation level [11]. For comitant exotropia, previous evidence suggested varying patterns in binocular accommodation and convergence, with some studies reporting insufficient [12–14], and others reporting heightened levels [15, 16]. Furthermore, previous reports showed distinct and varied binocular visual functions in different subtypes of IXT [13, 17], the underlying mechanisms which remained poorly understood.

The role of anterior segment biometric parameters in accommodation has been explored across various populations, including individuals with presbyopia [18], myopia [19], refractive accommodative esotropia [20], and AACE [21]. However, there has been no report on investigations on these parameters specifically in relation to different types of IXT. Patients with different types of IXT often have great differences between exodeviation for near and for distance, theoretically creating a different demand on the vergence system and potentially affect the accommodation system through the crosslink interaction between accommodative and vergence systems [22]. Such differences relating to AC/A ratio [23], accommodative facility (AMF) [24] and accommodative response [24] were reported in previous studies. Considering the corresponding changes of ocular biometry following the accommodation which was proposed by Richdale et al. [25] and Khan et al., [26] it could be reasonably postulated that the ocular biometric parameters vary among subtypes of IXT. There seems to be a pressing need for clinical evidence on the association between ocular biometry, accommodation and subtypes of IXT.

This study examined the association between ocular biometric parameters and different IXT subtypes in children. By comparing these characteristics between children with IXT and orthophoria controls, as well as among IXT subtypes, this study aimed to enhance clinicians' ability to identify IXT subtypes and deepen understanding of the condition's pathophysiology, classification and interventions. Considering the correlations between ocular accommodation and development of myopia [27], this study might contribute to the evaluation of intervention strategies that could mitigate the progression of myopia in children with different subtypes of IXT.

Methods

Study population

This cross-sectional study enrolled outpatients aged from 8 to 12 years who visited the Department of Strabismus and Pediatric Ophthalmology at Beijing Tongren Hospital between September 2022 and September 2023. Inclusion and exclusion criteria are provided in Table 1. The normal controls with straight ocular alignment were the children who visited the department for intentions of vision screening. Written informed consent was obtained from parents or legal guardians of each participant prior to enrollment. Ethical approval was granted by the Institutional Review Board of Beijing Tongren Hospital, Capital Medical University (approval number: TRECKY2020-142).

Study protocol and clinical procedures

Gender, age and medical history were collected from parents. Slit-lamp and fundus exams ruled out segment diseases.

Refraction examination: Cycloplegic refraction was measured with the Topcon RM-800 after (Topcon Corp, Tokyo, Japan) administering 1% cyclopentolate (Cyclogyl, Alcon Health care S.A.) and tropicamide drops (Mydrin P, Santen, Osaka, Japan). It was defined as the spherical equivalent refraction (SE; SE = spherical power + cylinder power/2).

Ocular biometry: Ocular biometry was measured under scotopic conditions with the Lenstar LS-900 (Haag-Streit, Bern, Switzerland), which has been described elsewhere previously [28, 29]. A fully qualified optometrist performed all measurements. The participants were asked to fixate on the internal red light of the device (which was generally considered as a non-accommodative target), and the non-measured eye was occluded. The Lenstar LS-900 system automatically obtained three consecutive measurements per eye and determined axial length (AL), flat keratometry (Kf),

Table 1 Inclusion and exclusion criteria

Inclusion criteria
1. 8–12 years old
2. Diagnosed with intermittent exotropia (exodeviation angle at near and distance was both more than 15PD), or with straight ocular alignment* (exophoria less than 5PD)
3. No previous ophthalmic surgery for any reason, including strabismus surgery or botulinum injection
4.Subjects could cooperate with ophthalmologic examinations, the guardians understood content of this research and were willing to sign the informed consent forms
Exclusion criteria
1. Other kinds of strabismus, such as vertical deviation of more than 5PD, dissociated vertical deviation (DVD), A- or V-pattern strabismus, paralytic or restrictive exotropia
2. Ocular or neurologic disorders, such as congenital cataract and attention deficit hyperactivity disorder
3. Amblyopia (monocular distant vision worse than 20/25), anisometropia greater than 2.0D or astigmatism greater than 2.0D
4. Complaining of obvious ocular discomfort possibly relating to accommodative anomalies, such as sore eye or eye pain
5. Refractive errors exceeding −6.00D (myopia) or +2.00D (hyperopia)
6. Treatment which could influence accommodation and ocular biometry, including orthokeratology lenses, low-dose atropine, training of accommodation and convergence

PD prism diopters, *D* diopters

* The normal controls with straight ocular alignment were the children who visited the department for intentions of vision screening

steep keratometry (Ks), central corneal thickness (CCT), aqueous depth (AD), lens thickness (LT) and pupil diameter (PD). Mean keratometry (Km) was defined as the average of Kf and Ks.

Strabismus examination: Exotropia deviation and Newcastle score (NCS) [30] were measured with cover tests at 6 m and 33 cm after full refractive correction and 1-h monocular occlusion.

Accommodation and convergence function evaluation: Tests involved accommodative amplitude (AMP), accommodative facility (AMF), accommodative response, near point of convergence (NPC) and accommodative convergence/accommodation ratio (AC/A ratio). The monocular AMP was measured with the minus lens method at a distance of 40 cm. Minus lenses were added continually until unchangeable blurring was reported. The sum of the absolute dioptric value of minus lens for blur and the dioptric equivalent of the viewing distance (+2.5D) was recorded as the AMP. The AMF was tested by the ±2.0D flip method. The subjects were asked to recognize the near visual target (20/30) 40 cm away with full-correction spectacles and a flipper. The test was started with a +2.0D flipper, and patients were required to switch to −2.0D as soon as the target was identified clearly and then back to +2.0D. The number of flips clearing both plus and minus lenses was considered one cycle. The number of cycles per minute (cpm) was recorded. The accommodation response was measured via the monocular estimation method (MEM). A special card with a text paragraph in Chinese language was attached to the retinoscope, which was designed to be the same as the Bernell Corporation MEM card. The patients were required to read the text at 40 cm, while the examiner estimated the retinoscopic reflex in the horizontal meridian. Trial lenses were added until a neutral solution was reached. The corresponding lag or lead of accommodation was recorded. The accommodation responses of all patients were assessed by an experienced examiner. For NPC, the subjects were told to fixate on an accommodation target 40 cm in front of the eyes. The target was allowed to move slowly toward the eyes until diplopia was reported or one eye drifting outward was found. The distance from this point to the plane of the subject's spectacles was measured. The test was repeated twice, and the average was recorded as the NPC. The stimulus AC/A ratio was tested via the synoptophore method right after prism and alternate cover testing. The macular simultaneous perception slides (images of a lion and cage, angle subtended: 3 degree) were used to subjectively measure deviation by asking the participant to use the tube to move the lion into the cage. The deviation was measured with complete corrected spectacles and measured again with −3.0D lenses added. The AC/A ratio was calculated by dividing the difference in deviation between two conditions by −3.0D.

Of the initial participants, 14 were excluded for clinical reasons and 25 for unmeasurable biometry results, resulting in 379 IXT cases and 122 orthophoric controls (shown in Table 1). Only the data from the right eye were included in the statistical analysis.

Grouping criteria

Children with orthophoria were assigned to Group A. IXT subjects were classified into three groups based on the near-distance exodeviation difference after diagnostic occlusion as described by Burian [9]: A patient who had an exodeviation which was essentially of the same amount in distance and near fixation was classed as having a *basic type*. A patient whose deviation was greater for near than for distance by no less than 10 prism diopters was grouped under the heading of *convergence insufficiency (CI)*. A patient whose deviation was larger for distance than for near by no less than 10 prism diopters was considered to be of the *divergence excess (DE) type*. According to this, Group B included patients with the basic type of IXT; Group C, consisted those with the CI type; and Group D included those with the DE type.

Data analysis

Statistical analyses were conducted using SPSS version 29.0 (SPSS, Inc., Chicago, IL, USA). Normality of the data was assessed with the Shapiro–Wilk test, and variance homogeneity was tested using the Levene test. Continuous variables were compared across groups using ANOVA or Kruskal–Wallis tests, with Bonferroni-adjusted post hoc comparisons for pairwise group differences. Categorical variables were analyzed with chi-square tests. Univariate and multivariate logistic regression analyses were used to assess correlations between IXT (orthophoria or basic IXT) and IXT subtypes (basic or CI) with various parameters. Variables with a significance level of $P < 0.10$ in univariate analysis were included in multivariate regression. A two-tailed model was used, with statistical significance set at $P < 0.05$.

Results

Demographic description of participants

A total of 540 children aged from 8 to 12 years were recruited, 501 completed ocular examinations, including 379 with IXT and 122 orthophoria controls. The mean age was 9.27 ± 1.23 years, with 253 patients (50.5%) were male. Among the IXT participants, 254 (67.0%) diagnosed with the basic type, 92 (24.3%) with CI type, and 33 (8.7%) with DE type.

Differences among IXT subtypes

The CI type showed significantly greater lens thickness compared to the basic and the DE types ($P = 0.002$; $P = 0.026$; Table 2, Fig. 1). Other ocular biometric parameters, including AL, keratometry, CCT, AD, and PD, showed no significant differences across groups (all $P > 0.05$). The AC/A ratio was significantly lower in CI IXT compared to that in basic type, with mean values of 2.03 ± 1.29 PD/D vs. 2.72 ± 2.16 PD/D, respectively ($P = 0.016$).

Univariate logistic regression analysis indicated that CI IXT was associated with greater lens thickness (OR = 8.767, $P = 0.006$) and lower AC/A ratio (OR = 0.807, $P = 0.006$). These associations remained significant in multivariate logistic regression after adjusting for age, sex, and SE (Table 3).

Differences between IXT and orthophoria controls

As shown in Table 2 and Fig. 1, basic IXT children had greater AMPs than orthophoria controls (9.16 ± 5.22 D vs. 7.77 ± 3.28 D, $P = 0.004$). Basic IXT children also demonstrated less lag of accommodation [0.75(0.50, 0.75)] compared with controls [0.75 (0.75, 1.00)] ($P = 0.006$). The NPC for basic IXT was 8.86 ± 5.66 cm, significantly greater than controls at 7.19 ± 3.69 cm ($P < 0.001$).

Univariate logistic regression showed that basic IXT was associated with farther NPC (OR = 1.087, $P = 0.004$), greater AMP (OR = 1.132, $P = 0.001$), and less lag of accommodation (OR = 0.330, $P = 0.002$) compared to controls. These associations were confirmed in multivariate analyses after adjusting for age, gender and SE (Table 4).

Discussion

To our knowledge, this is the first study to investigate the association between ocular biometric parameters and specific types of intermittent exotropia (IXT) in children, examining key parameters related to accommodation and convergence. We found that lens thickness (LT) was significantly greater in children with the convergence insufficiency (CI) type of IXT, suggesting that this parameter may serve as a clinical marker for this subtype. Additionally, amplitude of accommodation (AMP), accommodative response, and near point of convergence (NPC) differed significantly between children with IXT and orthophoria controls, highlighting potential markers for diagnosing and understanding the pathophysiology of exotropia.

In this study, the basic type of IXT was the most prevalent (67.0%), followed by CI (24.3%) and divergence excess (DE) (8.7%), consistent with previous findings on childhood IXT demographics [31, 32]. The exclusion of simulated divergence excess cases ensured a more precise classification, crucial for determining the most effective treatment. Identifying IXT subtype is critical in clinical settings, as tailored surgical approaches are recommended. While studies like those by the Pediatric Eye Disease Investigator Group (PEDIG) have reported comparable success rates for different surgical techniques in basic IXT [33], debates remained on the optimal methods for each subtype [34, 35] with options like

Table 2 Differences of parameters among orthophoria subjects and different types of IXT children (mean ± SD)/[M(P25,P75)]

Parameters	Group A Orthophoria controls (*n* = 122)	Group B Basic type of IXT (*n* = 254)	Group C CI type of IXT (*n* = 92)	Group D DE type of IXT (*n* = 33)	*P* values
Age (years)	9.43 ± 1.25	9.20 ± 1.19	9.24 ± 1.23	9.36 ± 1.48	0.378†
Sex (male/all)	64/122	124/254	47/92	18/33	0.872¶
Exotropia deviation (PD)					
33 cm	–	−42.62 ± 15.90	−48.37 ± 19.68	−32.97 ± 10.84	<**0.001**†
6 m	–	−39.84 ± 16.13	−37.61 ± 20.06	−42.97 ± 11.35	0.272†
Average for near and distance	–	−41.23 ± 15.95	−42.99 ± 19.85	−38.13 ± 11.18	0.351†
Newcastle score	–	4.38 ± 1.88	4.33 ± 1.83	3.85 ± 1.68	0.296†
SE (D)	−1.71 ± 1.44	−1.70 ± 1.76	−1.39 ± 1.78	−1.59 ± 1.55	0.439†
AL (mm)	24.20 ± 0.95	24.19 ± 1.02	24.10 ± 1.04	24.28 ± 0.76	0.812†
Km (D)	43.49 ± 1.47	43.45 ± 1.49	43.24 ± 1.55	43.30 ± 1.52	0.573†
CCT (mm)	548.55 ± 35.97	543.79 ± 33.17	547.21 ± 32.14	538.12 ± 26.83	0.321†
LT (mm)	3.35 ± 0.11	3.34 ± 0.15	3.39 ± 0.17	3.33 ± 0.09	**0.018**†
AD (mm)	3.23 ± 0.20	3.23 ± 0.22	3.22 ± 0.43	3.24 ± 0.17	0.955†
PD (mm)	5.43 ± 0.94	5.50 ± 0.83	5.63 ± 0.80	5.39 ± 0.65	0.333†
AMP (D)	7.77 ± 3.28	9.16 ± 5.22	8.82 ± 2.90	10.05 ± 3.15	**0.010**†
AMF (cpm)	7.59 ± 3.09	7.37 ± 3.14	6.82 ± 3.29	7.33 ± 3.31	0.352†
Accommodative Response (D)	0.75 (0.75,1.00)	0.75 (0.50,0.75)	0.75 (0.50,0.75)	0.75 (0.50,0.94)	**0.003**§
NPC (cm)	7.19 ± 3.69	8.86 ± 5.66	9.09 ± 6.61	9.19 ± 7.15	**0.028**†
AC/A ratio (PD/D)	2.30 ± 1.27	2.72 ± 2.16	2.03 ± 1.29	2.41 ± 2.22	<**0.001**†

Parameters	*P* values					
	Between controls and basic type IXT	Between controls and CI type IXT	Between controls and DE type IXT	Between basic type IXT and CI type IXT	Between basic type IXT and DE type IXT	Between CI type IXT and DE type IXT
AC/A (PD/D)	0.189‡	0.732‡	0.992‡	**0.016**‡	0.802‡	0.755‡
NPC (cm)	**0.037**‡	0.088‡	0.410‡	1.000‡	1.000‡	1.000‡
LT (mm)	0.470‡	**0.042**‡	0.412‡	**0.002**‡	0.664‡	**0.026**‡
AMP (D)	**0.004**‡	0.080‡	**0.007**‡	0.513‡	0.264‡	0.158‡
Accommodative response (D)	**0.006**§	**0.010**§	0.263§	1.000§	1.000§	1.000§

Significant factors appear in boldface. Continuous variables are reported as mean ± SD

IXT intermittent exotropia, *CI* convergence insufficiency, *DE* divergence excess, *PD* prism diopters, *NPC* near point of convergence, *AC/A ratio* accommodative convergence-to-accommodation ratio, *SE* spherical equivalent, *D* diopters, *AL* axial length, *Km* mean keratometry, *CCT* central corneal thickness, *LT* lens thickness, *AD* aqueous depth, *PD* pupil diameter, *AMP* accommodative amplitude, *AMF* accommodative facility, *cpm* cycles per minute

† One-way ANOVA test

‡ Parametric post hoc test (Bonferroni's test)

§ Kruskal–Wallis test

¶ χ^2 test

slanted bilateral lateral rectus recession (SBLR) for CI IXT [36] and augmented bilateral lateral rectus recession (aBLR) for DE IXT [37] showing promise in reducing specific deviations.

Ocular biometry was measured by one single Lenstar LS-900 device to allow direct comparisons among children examined. Previous studies have demonstrated that the ocular biometric parameters changed during short-term accommodation for orthophoria, mainly including decreasing AD [38, 39] increasing LT [38, 39] with increasing levels of accommodation. All participants (including both IXT children and controls) were asked to fixate on the internal red light of the device (which was generally considered as a non-accommodative target [40]) to avoid the influence of accommodation. To avoid

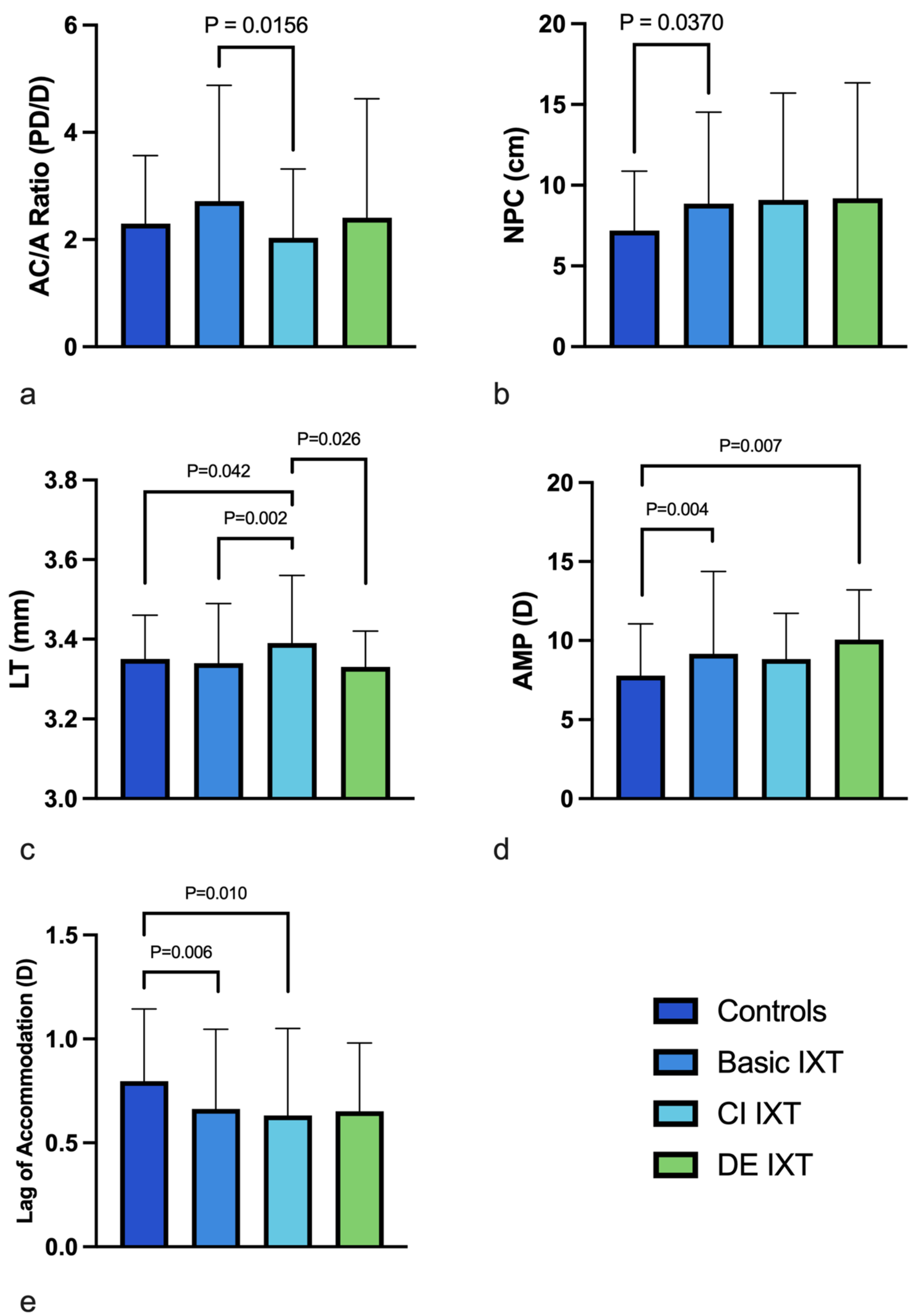

Fig. 1 Differences in parameters among orthophoria and different types of IXT in children. **a** The AC/A ratio was significantly lower in the CI type IXT compared to the basic type. **b** The NPC was farther in the basic type IXT compared to controls. **c** The lens was thicker in the CI type IXT compared to other groups. **d** The AMP was significantly greater in basic type IXT than in controls. **e** The lag of accommodation was significantly less in basic type IXT compared to controls. *IXT* intermittent exotropia, *LT* lens thickness, *CI* convergence insufficiency, *AMP* accommodative amplitude, *AC/A ratio* accommodative convergence-to-accommodation ratio, *NPC* near point of convergence

Table 3 Logistic regression analysis of the associations between parameters and types of IXT (basic type or CI type) (*n* = 346)

Parameters	Univariate logistic regression			Multivariate logistic regression		
	OR	95% CI	*P* value	OR	95% CI	*P* value
AC/A ratio (PD/D)	0.807	0.691, 0.942	**0.006**	0.807	0.692, 0.942	**0.007**
NPC (cm)	1.007	0.967, 1.048	0.748			
AMP (D)	0.981	0.920, 1.045	0.554			
Accommodative response (D)	0.823	0.442, 1.533	0.539			
LT (mm)	8.767	1.854, 41.461	**0.006**	9.907	1.912, 51.343	**0.006**

Multivariate logistic regression was adjusted by age, gender and SE

Significant factors appear in boldface

IXT intermittent exotropia, *CI* convergence insufficiency, *AC/A ratio* accommodative convergence-to-accommodation ratio, *NPC* near point of convergence, *AMP* accommodative amplitude, *LT* lens thickness.

Table 4 Logistic regression analysis of the associations between parameters and IXT (orthophoria or basic type IXT) (*n* = 376)

Parameters	Univariate logistic regression			Multivariate logistic regression		
	OR	95% CI	*P* value	OR	95% CI	*P* value
AC/A ratio (PD/D)	1.121	0.960, 1.310	0.159			
NPC (cm)	1.087	1.027, 1.151	**0.004**	1.091	1.030, 1.155	**0.003**
AMP (D)	1.132	1.050, 1.221	**0.001**	1.139	1.055, 1.230	<**0.001**
Accommodative response (D)	0.330	0.161, 0.674	**0.002**	0.309	0.147, 0.651	**0.002**
LT (mm)	0.543	0.108, 2.719	0.458			

Multivariate logistic regression was adjusted by age, gender and SE

IXT intermittent exotropia, *CI* convergence insufficiency, *AC/A ratio* accommodative convergence-to-accommodation ratio, *NPC* near point of convergence, *AMP* accommodative amplitude, *LT* lens thickness

Significant factors appear in boldface

the influence of fusional vergence, the non-measured eye accepted monocular occlusion.

Our finding of increased LT in children with CI type IXT is particularly notable. Children with CI IXT need to make more effort to maintain eye alignment for near, and theoretically this may create a high demand on the vergence system and potentially affect the accommodation system through the crosslink interaction between the accommodative and vergence systems [22]. The fact that the increased LT is correlated with CI type IXT seems to support this hypothesis. Previous studies indicate that accommodation leads to changes in ocular biometry, including decreased aqueous depth (AD) and increased LT [25, 26]. This thickening may be attributed to ciliary muscle tension and lens elasticity, which increase with accommodation demand [25, 26, 41]. In CI type IXT, disparity cues can be a major drive to accommodation via the convergence accommodation-to-convergence (CA/C) linkage [42]. Greater convergence effort is likely required, following greater convergence accommodation could contribute to the observed LT increase. Although LT was measured without active accommodation stimulus, it is plausible that tonic convergence, necessary for maintaining alignment, may induce a lasting effect on LT, potentially reflecting prolonged accommodative spasm [43] (Fig. 2). This hypothesis could partly be supported by the observation of myopic shift when switching from monocular to binocular fixation during the control of distance exotropia for near fixation in IXT patients [44].

However, it is also possible that increased LTs found in CI type IXT were causes rather than effects of convergence insufficiency and lower AC/A ratio. The primarily anatomically thicker lens might contribute to harder blur-driven accommodation, following harder accommodative convergence and lower AC/A ratio. This theory was in accordance with several previous researches. Rutstein et al. [45] found that accommodation was severely affected when exotropic children lost control of their exodeviation, but relatively orthophoria existed when accommodative ability was adequate. Thus, they attributed the intermittent exotropia to a defect of accommodation, rather than under-accommodation resulting from loss of convergence. Moreover, over-minus lens treatment in clinical practice is believed to work by stimulating accommodation and through accommodation, accommodative convergence, thus favoring the control of the deviation in IXT [46]. It is debated if in CI type

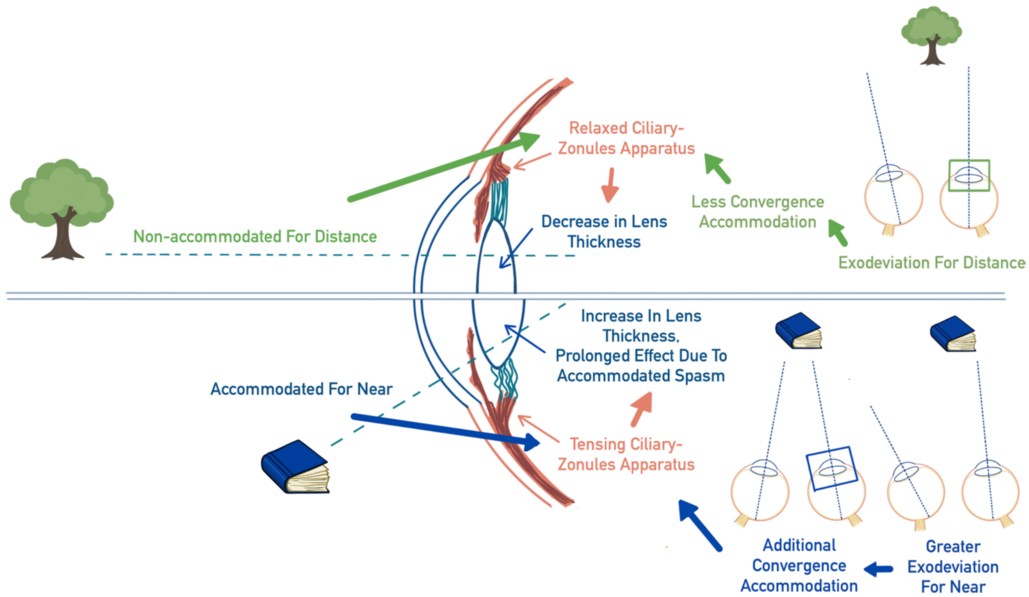

Fig. 2 Schematic illustration of LT changes relating to accommodation stimulus in CI IXT. Children with CI IXT tended to make greater accommodative effort to maintain binocular vision when fixating from distance to near task. The increase in LT was supposed to be resulted from tensing of ciliary body–zonules apparatus and pulling of lens during accommodation. Given the accommodative spasm and excess convergence related to near-task and ocular exodeviation, it is possible that the tense ciliary–zonules apparatus and thick lens during accommodation could have prolonged effect over time, thus observed by the device. *Thick arrow* displays the mechanistic insights and hypotheses. *Thin arrow* points to crystalline lens and ciliary body–zonules apparatus. *IXT* intermittent exotropia, *LT* lens thickness, *CI* convergence insufficiency

IXT, the control of the deviation is mainly warranted by accommodation through the AC/A ratio or by fusional vergence through the CA/C ratio, in other words, the increased LTs were causes or effects in larger deviations for near. Considering CA/C ratio is difficult to measure and is not routinely assessed in the clinical practice, the specific role of AC/A ratio and lens thickness in CI type IXT remains unclear.

In basic type IXT, we observed that AMP was greater, lag of accommodation was lower, and NPC was farther compared to orthophoria controls. These findings align with previous studies in British [44] and Korean [47] populations, which suggested that increased vergence demand in basic IXT might drive stronger accommodation to stabilize vision at near (AMP and accommodative response represented the maximum ability of accommodation and ability focusing on a stationary target, respectively, which could be influenced by accommodation demand [48]). However, LT measurements did not reflect similar accommodation-driven changes between basic IXT and controls, suggesting that children with basic IXT may have sufficient recovery of the crystalline lens following accommodation stimulus such as near tasks. In contrast, CI type IXT children may experience chronic accommodation and convergence strain, contributing to their increased LT in the current study.

These findings suggest that LT, AMP, and NPC could serve as clinical indicators for managing IXT subtypes. Children with CI IXT seem make more effort to accommodate for near, and this may cause prolonged accommodative spasm. As a result, a lasting increased LT was found. The observed differences in parameters relating to LT and accommodation could contribute to a deeper understanding of the CI type versus basic types of IXT, potentially informing decisions on targeted interventions. For instance, greater LT and lower AC/A ratio in CI type IXT may support the use of surgical techniques like SBLR to manage near-distance deviation, or non-surgical techniques to relax accommodative spasm. For basic IXT, understanding the heightened accommodative capacity might influence non-surgical approaches, especially for managing convergence demands.

This study has limitations, including sample size disparities among IXT subtypes. Although statistical tests confirmed normality and variance homogeneity, a more balanced sample may enhance result reliability. Another limitation might be the recruitment of participants. Although the majority of normal controls came to the department for ocular visual screening and children complaining of obvious ocular discomfort have been excluded, their functions relating to accommodation might not fully represent the normal level. This study relied on LT as the primary biometric measure without assessing other relevant parameters, such as lens location or ciliary muscle thickness. Additionally, accommodation stimulated by a slide with angle subtended of 3 degree was influenced by the depth of focus when measuring AC/A ratio with synoptophore. One single slide was used for all participants to reduce the possible inaccuracy of stimulus method. Future studies incorporating advanced imaging tools to capture these features could offer a more comprehensive understanding of morphological adaptations in IXT. The existing knowledge suggests that the accommodative function and the characteristics of ocular biometry could be a promising IXT-monitoring tool and should be further explored by future studies.

Conclusions

In summary, this study provides new insights into the biometric and accommodative characteristics of IXT subtypes in children. Increased LT and lower AC/A ratios in CI type IXT, alongside AMP and NPC differences in basic type IXT, could serve as valuable clinical markers for diagnosing and managing IXT. These findings contribute to a deeper understanding of the pathophysiology of IXT and may inform more tailored and effective treatment strategies for affected children.

Abbreviations

IXT	Intermittent exotropia
CI	Convergence insufficiency
DE	Divergence excess
PD	Prism diopters
AACE	Acquired comitant esotropia
NPC	Near point of convergence
AC/A ratio	Accommodative convergence-to-accommodation ratio
CA/C ratio	Convergence accommodation-to-convergence ratio
SE	Spherical equivalent
D	Diopters
AL	Axial length
Km	Mean keratometry
Kf	Flat keratometry
Ks	Steep keratometry
NCS	Newcastle score
CCT	Central corneal thickness
LT	Lens thickness
AD	Aqueous depth
PD	Pupil diameter
AMP	Accommodative amplitude
AMF	Accommodative facility
MEM	Monocular estimation method
cpm	Cycles per minute
SBLR	Slanted bilateral lateral rectus recession
aBLR	Augmented bilateral lateral rectus recession

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Author contributions
All authors contributed to the study conception and design. The study was designed by Jing Fu, Jing-Xin Li, Xiang-Xiang Liu and Jie Hao. Material preparation and data collection were performed by Jing-Xin Li, Hui-Xin Li, Yi-Yang Zhao, and Yu-Meng Wang. The statistical analysis was made by Jing-Xin Li and consulted by Feng-Chao Zhou and Lei Li. The first draft of the manuscript was written by Jing-Xin Li and Xiang-Xiang Liu. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability
The data that support the findings of the current study are not publicly available due to their containing information that could compromise the privacy of research participants, but are available from the corresponding author Jing Fu.

Declarations

Ethics approval and consent to participate
This study followed the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of Beijing TongRen Hospital (approved number: TRECKY2020-142). Written informed consent to participate was obtained from the parents or legal guardians of any participant prior to participation.

Consent for publication
Not capable.

Competing interests
The authors declare no competing interests.

Author details
[1]Beijing Tongren Eye Center, Beijing Tongren Hospital, Capital Medical University, Beijing Key Laboratory of Ophthalmology & Visual Sciences, Dongjiaominxiang Street 1#, Dongcheng District, Beijing 100730, China.

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