

Incorporating Diplopia Scoring into Patient-Centered Binocular Vision Assessment for Acute Acquired Concomitant Esotropia

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Abstract

Background

To investigate whether incorporating diplopia scoring into binocular vision assessment can provide a more patient-centered adjunct for managing acute acquired concomitant esotropia (AACE).

Methods

A prospective cohort study was conducted from January 2022 to January 2026. Of 177 consecutive enrolled AACE patients, 36 were excluded because they reported a baseline diplopia frequency lower than "sometimes" for reading and/or for straight ahead distance. All patients received a single 2.5IU botulinum-toxin-type-A (BTX-A) injection into bilateral medial rectus and follow-up were scheduled at 1 month, 3 months and 6 months. Comprehensive examinations were recorded including deviation angles measured by prism and alternate cover test at 33cm and 6m, fusional vergence ranges assessed using a comprehensive refractor (synoptophore substitution for > 40 PD at distance), stereoacuity evaluated via synoptophore (distance) and random dot stereograms (near), and diplopia severity quantified using a revised Diplopia Questionnaire (score 0–40), with emphasis on reading and straight-ahead distance gaze. All analyses were performed using the R program (Version 4.3.2) ($P < 0.05$).

Results

When diplopia scoring was incorporated into the binocular vision evaluation for AACE, 20.57% (distance) versus 6.38% (near) of patients had deviation angles ≤ 10 PD but presented with moderate to severe diplopia. Additionally, some patients with measurable stereopsis still experienced prominent diplopia: at near, this affected 23.38% of patients in qualitative assessment and 27.27% in quantitative assessment; at distance, it affected 99.06% of patients at baseline in qualitative assessment. After BTX-A treatment, when diplopia scoring was incorporated, the proportion of patients with at least moderately severe diplopia and deviation angles ≤ 10 PD rose from 6.25% to 40% at distance by 6 months. Among patients with deviation angle ≤ 10 PD and regained stereopsis, distance diplopia still persisted (21.43–25%). Near diplopia resolution rates remained high (96.59–97.71%), while distance resolution declined from 93.89% to 71.59% at 6 months. Crucially, symptom improvement rates of binocular vision based on diplopia resolution criteria substantially exceeded stereopsis-based criteria across all visits and distances.

Conclusions

Incorporating diplopia scoring into binocular vision assessment addresses the limitations of stereopsis alone by capturing symptom-sign dissociation and distance-near disparities, supporting its adoption as a patient-centered adjunct in AACE evaluation and follow-up.

Introduction

In recent years, awareness of acute acquired concomitant esotropia (AACE) has grown substantially worldwide(1, 2). Clinically, AACE is characterized by the sudden onset of concomitant esotropia accompanied by binocular diplopia(3, 4). Burian and Miller originally classified the condition into three subtypes (Swan, Burian–Franceschetti, and Bielschowsky types) based on clinical presentation and etiology. Treatment success is conventionally defined as a residual horizontal deviation of 10 prism diopters (PD) or less, along with documented binocular single vision(4–7). However, a distinct and clinically challenging subset of AACE patients presents with disproportionately severe diplopia despite only mild or even sub-threshold deviation. While symptoms and signs typically co-evolve in most diseases, their dissociation is not uncommon in ophthalmology. A comparable scenario exists in AACE patients with minimal to moderate strabismus but severe diplopia. This observation underscores that the magnitude of deviation alone is insufficient as the sole criterion for therapeutic decision-making or post-intervention evaluation in AACE.

Equally challenging is the objective assessment of binocular vision. Previous studies have used fine stereopsis as a proxy for binocularity(8, 9). However, stereopsis (defined as the relative depth ordering of objects) can occasionally coexist with binocular diplopia. Indeed, accumulating evidence indicates that many AACE patients retain fine stereopsis even before treatment, despite ongoing diplopia(9, 10). In a cohort of 276 AACE patients, 109 demonstrated normal pretreatment stereopsis. Similarly, another study reported that 58.9% of affected adults and 43.9% of adolescents exhibited fine distance stereopsis, whereas good near stereopsis was observed in 23.2% and 16.2% of adults and adolescents, respectively. These findings suggest that sensory success defined solely by stereopsis restoration may

inadequately capture the full spectrum of binocular recovery in AACE, even though these patients are generally considered to have favorable potential for binocular function restoration.

From the patient's perspective, binocular diplopia is the most direct and distressing manifestation of impaired binocular single vision. Current clinical assessments of diplopia rely primarily on objective tools such as the Goldmann perimeter, Hess screen, Lancaster red-green test, Bagolini striated lens test, or qualitative questionnaires to determine whether diplopia is present or absent. Nevertheless, these methods lack sensitivity to dynamic quantitative changes in symptom severity over time. To address this gap, Holmes et al.(11) developed a revised diplopia questionnaire with a data-driven scoring algorithm, enabling quantitative and position-specific evaluation of diplopia frequency across seven gaze positions, particularly relevant for AACE patients who often report diplopia during reading (near) or straight-ahead (distance) viewing. Despite its promise, this scale has rarely been applied in the AACE population.

This study aimed to investigate whether incorporating diplopia scoring into binocular vision assessment provides a more patient-centered adjunct for the management of AACE. We hypothesize that quantitative diplopia scoring can serve as a valuable adjunct indicator for evaluating binocular vision in AACE management for both treatment decision-making and post-intervention follow-up, particularly in patients presenting with severe diplopia symptoms but mild to moderate signs.

Methods

A prospective cohort study was conducted from January 2022 to January 2026 at Beijing Tongren Hospital, Capital Medical University. The study was conducted in accordance with the Declaration of Helsinki, and the study was approved by the Institutional Review Board of Beijing Tongren Hospital, Capital Medical University (TREC2022-KY020). Written informed consent was obtained from the patients or guardians. The study was registered on the Chinese Clinical Trial Registry (<http://www.chictr.org.cn>; ChiCTR2100053717).

AACE was defined by a sudden inward deviation of the eye and the onset of binocular diplopia. The inclusion criteria were AACE patients with a confirmed date of deviation onset, a single botulinum toxin type A (BTX-A) injection as the first treatment-line, normal eye movement in each direction, horizontal binocular diplopia with equal separation of images in all directions, and binocular diplopia prior to BTX-A treatment had to be at least moderately severe, defined as the patient rating diplopia frequency as either "sometimes" or worse for reading and/or for straight ahead distance on the Diplopia Questionnaire(11, 12). Informed consent was obtained from patients or guardians voluntarily. Exclusion criteria were patients with extraocular muscle paralysis or ocular motility limitation, accommodative dysfunction or decompensated accommodative esotropia, presence of esotropia related to intracranial pathology or any other ophthalmic, systemic, or neurologic diseases, involvement of vertical strabismus or nystagmus, and a history of strabismus, intraocular surgery or BTX-A injections.

All participants underwent comprehensive ophthalmic examinations including BCVA, refractive status, cover test, eye movement and assessment of anterior and posterior segment. The refractive error was measured using cycloplegic refraction (age < 40 years) or manifest refraction (age ≥ 40 years), and the spherical equivalent error was calculated as the algebraic sum of the dioptric powers of the sphere and half of the cylinder. The angle of deviation was measured by a prism and alternate cover test at 33cm and 6m. All patients underwent cranial MRI to exclude intracranial pathology and neurological diseases.

Fusional vergence range was taken at near and distance fixation with myopic refractive correction on a comprehensive refractor (CV3000; Topcon), respectively. The absolute value of the fusional vergence range was calculated by subtracting fusional convergence amplitude and fusional divergence amplitude(13). In addition, if the value exceeded 40 PD as measured on a comprehensive refractor, a synoptophore was used instead to measure the fusional vergence range at distance because of the limited maximum value obtainable with the comprehensive refractor, but this could not be applied to near fixation, as the synoptophore is designed for distance testing only.

Stereoacuity at distance fixation was qualitatively measured using synoptophore testing, while stereoacuity at near fixation was evaluated with the random dot stereograms test (Normal stereoacuity was quantitatively defined as ≤ 100 seconds of arc; No stereoacuity was qualitatively unable to perceive near stereoscopic vision by large visual field stereo-blindness screen stereogram).

The questionnaires were administered to assess binocular diplopia score (Diplopia Questionnaire, DQ), quality of life (construct validation of the amblyopia and strabismus questionnaire, A&SQ), and the time from disease onset to treatment and near-working hours. The binocular diplopia score was quantified using the revised diplopia questionnaire based on the design by Holmes et al(11). This diplopia questionnaire evaluated the severity of diplopia based on patient reports on seven gaze positions, including the patient's typical reading position, straight-ahead distance gaze, down, right, left, up, and any other gaze positions. Since AACE patients primarily complained of binocular diplopia in the reading position (near) and straight-ahead distance gaze position (distance), we mainly analyzed the scores for the reading position and straight-ahead distance gaze in this study. The scores ranged from 0 (never), 2 (rarely), 20 (sometimes), 30 (often), and 40 (always). In this study, binocular diplopia prior to BTX-A was required to be at least moderately severe ("sometimes" or worse), thus the

improvement was defined as a reduction in diplopia frequency to “rarely” or “never”. Accordingly, the successful resolution rate of diplopia was calculated as the proportion of patients with diplopia scores improved to “never” or “rarely” at follow-up. For patients who did not visit the clinic during follow-up, the diplopia questionnaire interviews were conducted through telephone.

BTX-A injections were performed without electromyographic guidance or conjunctival incision, by a single surgeon (J.F.) with the patient under either general or local anesthesia based on their age and level of cooperation. BTX-A (BOTOX®, Allergan, Inc., Irvine, California, US) was diluted with physiological saline to a concentration of 2.5 IU. The procedure was performed by instructing the patient to look outward or pulling the eye in the opposite direction of the target muscle, injecting a 30G needle through the conjunctiva starting from the approximate muscle insertion into the bilateral medial rectus. The needle was advanced along the muscle until 8–10 mm behind the limbus, with 0.1 ml volume injected into each muscle. In this study, because re-treatment with any repeat BTX-A injection was considered non-successful, only a single BTX-A intervention was analyzed, with follow-up evaluations conducted at 1 month, 3 months, and 6 months after BTX-A treatment.

Statistical Analysis

For continuous variables, basic statistical descriptions were made using mean and standard deviation. For categorical data, frequency and percentage were used as basic statistical descriptions. ANOVA, Kruskal-Wallis rank sum test, or general linear mixed model was used to compare the continuous outcomes among groups, while Fisher's exact probability test was used for comparing categorical data. Univariable and multivariable logistic regressions were used to explore factors associated with the diplopia quantifying score. Repeated measurement analysis (linear mixed effects model) was used for the diplopia quantifying score and the quality of life score at different time points. All analyses were performed using the R program (Version 4.3.2), with $P < 0.05$ on both sides indicating statistical significant differences.

Results

Basic Characteristics of the Patients

This study initially consecutively enrolled 177 patients with AACE who received BTX-A injection as first-line therapy. After excluding those who did not report diplopia frequencies of at least “sometimes” at near or distance fixation on the baseline Diplopia Questionnaire, 141 patients were included in the final analysis. At baseline, near deviation angle was ≤ 40 PD in 95.74% of patients, while the corresponding proportion for distance deviation angle was 98.58%. The total Diplopia Questionnaire score was 53.63 ± 19.37 , comprising a near subscore of 8.55 ± 14.27 and a distance subscore of 35.83 ± 7.32 . The Bielschowsky type was the predominant clinical subtype (91.43%). Follow-up response rates for the Diplopia Questionnaire were 92.9% at 1 month, 80.1% at 3 months, and 62.4% at 6 months (Table 1).

Table 1
Basic Characteristics of the Patients and Associated Factors with Baseline Diplopia Score at Near and Distance

Variables	Near (univariate analysis)				Distance (univariate analysis)				Distance (multivariate analysis)		
	Mean ± SD	β	SE	P	Mean ± SD	β	SE	P	β	SE	P
Age(years)	30.15 ± 12.84	-0.0921	0.0939	0.7286	30.15 ± 12.84	0.0595	0.0481	0.2177	--	--	--
Sex(male/female)	66/75	-0.8400	2.4155	0.3285	66/75	1.2182	1.2348	0.3256	--	--	--
Deviation angle(PD)	17.45 ± 9.76	0.0030	0.1240	0.9804	19.42 ± 9.18	-0.1342	0.0671	0.0474	-0.0789	0.0725	0.2784
Spherical equivalent refraction(D)	-2.78 ± 2.33	-0.2622	0.5126	0.6098	-2.78 ± 2.33	-0.1864	0.2719	0.4941	--	--	--
Qualitative stereopsis	77 (66.4%)	1.3566	2.6197	0.6056	106 (77.4%)	4.0530	1.4715	0.0067	3.3849	1.5880	0.0349*
Near working hours/day	8.54 ± 2.99	-0.0001	0.0001	0.3404	8.54 ± 2.99	0.0000	0.0000	0.6280	--	--	--
Duration (years)	2.77 ± 2.67	-0.7508	0.5531	0.1779	2.77 ± 2.67	0.3034	0.2668	0.2584	--	--	--
Fusional vergence range(PD)	11.01 ± 6.55	-0.2610	0.2032	0.2024	13.18 ± 7.70	0.0053	0.0889	0.9527	--	--	--
Duration, the duration from symptom onset to treatment;Univariable and multivariable logistic regressions used to explore factors associated with the diplopia score											

Diplopia Scoring and Associated Factors at Baseline and Postoperative Follow-up

Figure 1 summarized the diplopia quantification scores, angles of deviation, and quality of life scores at baseline and at each postoperative follow-up time point. Over the follow-up period, both diplopia scores and deviation angles decreased significantly, demonstrating marked symptomatic relief ($P < 0.001$) and effective strabismus correction ($P < 0.001$). In post-hoc pairwise comparisons with Bonferroni correction, slight increases in diplopia scores and deviation angles were observed at 3 and 6 months, yet all post-treatment values remained significantly improved relative to baseline. Concurrently, quality of life scores increased significantly after BTX-A intervention ($P < 0.001$), confirming a substantial enhancement in patient well-being. Of additional note, diplopia scores were consistently higher at distance than at near across all time points (all $P < 0.01$), suggesting that symptoms are more pronounced in straight-ahead distance gaze that a pattern likely attributable to the fact that binocular diplopia in AACE typically first manifests under distance viewing conditions.

Furthermore, baseline diplopia score was set as the dependent variable, while age, sex, spherical equivalent, near working time, angle of deviation, fusional vergence range, qualitative stereopsis (near or distance), and duration from symptom onset to treatment were included as independent variables at baseline. In univariate analysis, no significant correlations were observed between near diplopia scores and any of the corresponding factors (all $P > 0.05$). At distance, however, both the angle of deviation ($P = 0.0474$) and qualitative stereopsis ($P = 0.0067$) showed significant correlations with diplopia scores. In the subsequent multivariate model, only qualitative stereopsis remained significantly associated with distance diplopia scores ($\beta = 3.3849$, $P = 0.0349$)(Table 1).

The Dissociation between Diplopia Symptoms, Deviation Angle and Stereopsis

When diplopia scoring was incorporated into the standard evaluation pathway for AACE, at baseline, 20.57% of patients had a deviation of ≤ 10 PD but a diplopia score of at least 20 (indicating at least moderately severe symptoms) during distance fixation, while the corresponding proportion for near fixation was 6.38%. Following BTX-A intervention, for near fixation, the proportion was 1.77% at 1 month, 1.45% at 3 months, and 4.88% at 6 months. In contrast, the corresponding proportions for distance fixation exhibited a pronounced and progressive escalation rising from 6.25% at 1 month to 16.92% at 3 months, and to 40% by 6 months (Table 2).

Among patients who retained stereopsis at baseline, a considerable proportion still experienced prominent diplopia symptoms (rated as at least "sometimes" or worse): qualitatively 23.38% and quantitatively 27.27% at near and qualitatively 99.06% at distance. Following BTX-A intervention, among patients with a near deviation angle ≤ 10 PD who had regained qualitative stereopsis postoperatively, none reported at

least moderately severe diplopia at any of the three follow-up time points (0% at 1, 3, and 6 months). Similarly, when applying a stricter quantitative criterion of normal stereoacuity (≤ 100 seconds of arc), the proportion of affected patients remained zero across all time points under near conditions. However, this favorable pattern did not extend to distance viewing that among patients meeting the same deviation and stereopsis criteria at follow-up, the proportion with clinically significant diplopia was 21.43% at 1 month, 22.22% at 3 months, and 25% at 6 months, indicating a persistently elevated symptomatic burden in the distance domain (Table 2).

Table 2
Diplopia Symptoms, Deviation angle and Stereopsis at Baseline and Postoperative Follow-up

Time	Near				Distance			
	Deviation angel $\leq$ 10PD but Binocular diplopia $\geq$ 20	Retained qualitative stereopsis but Binocular diplopia $\geq$ 20	Deviation angel $\leq$ 10PD who had regained qualitative stereopsis but Binocular diplopia $\geq$ 20	Retained quantitative stereopsis but Binocular diplopia $\geq$ 20	Deviation angel $\leq$ 10PD who had regained quantitative stereopsis but Binocular diplopia $\geq$ 20	Deviation angel $\leq$ 10PD but Binocular diplopia $\geq$ 20	Retained qualitative stereopsis but Binocular diplopia $\geq$ 20	Deviation angel $\leq$ 10PD who had regained qualitative stereopsis but Binocular diplopia $\geq$ 20
Baseline	6.38%	23.38%	--	27.27%	--	20.57%	99.06%	--
1 month	1.77%	--	0% (regained)	--	0%(regained)	6.25%	--	21.43% (regained)
3 months	1.45%	--	0%(regained)	--	0%(regained)	16.92%	--	22.22% (regained)
6 months	4.88%	--	0%(regained)	--	0%(regained)	40.00%	--	25.00% (regained)

Resolution Rate of Diplopia and Symptom Improvement Rate of Binocular Vision

The resolution rate for diplopia at near fixation reached 97.71% at 1 month, 97.35% at 3 months, and 96.59% at 6 months postoperatively. In contrast, the resolution rates for distance diplopia showed a progressively declining trend, decreasing from 93.89% at 1 month to 77.88% at 3 months, and further to 71.59% at 6 months.

In Fig. 2, for AACE patients who lacked preoperative stereopsis and achieved a postoperative deviation angle within 10PD, symptomatic improvement rate of binocular vision was evaluated through two distinct functional endpoints, stereopsis recovery and diplopia resolution. At near fixation, quantitative stereoacuity testing demonstrated symptom improvement rates of 58.93% at 1 month, 42.42% at 3 months, and 52.63% at 6 months when assessed against stereopsis recovery criteria. In contrast, when measured by diplopia resolution criteria, the corresponding rates were uniformly high, 100% at 1 month, 97.37% at 3 months, and 95.24% at 6 months. Qualitative stereoacuity testing yielded a similar pattern: improvement rates based on stereopsis recovery were 51.72%, 50.00%, and 72.73% at the three successive time points, whereas diplopia resolution criteria produced markedly higher rates of 100%, 100%, and 91.67%, respectively. For distance fixation, the improvement trajectory appeared considerably more modest under stereopsis-based definitions, with rates of 31.03% at 1 month, 29.41% at 3 months, and 37.50% at 6 months. Conversely, when diplopia resolution served as the benchmark, the corresponding rates were higher, 87.10%, 70.59%, and 66.67% over the same intervals. Collectively, these stratified analyses enabled a comparative appraisal of functional restoration across different viewing distances, while also illuminating the marked discrepancies arising from divergent criteria for therapeutic success.

Discussion

In this prospective cohort study, we systematically evaluated the utility of a quantified diplopia scoring system in patients with AACE who received BTX-A as a first-line intervention(14–17). Our findings demonstrate that while BTX-A effectively reduces deviation angle and recovers stereopsis, the degree of symptom relief does not fully align with traditional objective endpoints. Importantly, we observed that incorporating diplopia scoring into binocular vision assessment addresses the limitations of stereopsis alone by capturing symptom-sign dissociation and distance-near disparities, and diplopia quantification provides complementary information to deviation angle and stereopsis for guiding treatment decisions and assessing functional outcomes. The binocular diplopia symptom using a quantifying score developed by Holmes et al.(11, 18, 19) can be used to effectively quantify patient-reported diplopia frequency(12), and estimate the severity

of binocular diplopia and its changes over time with treatment. In the revised diplopia questionnaire(11), straight-ahead and reading positions were weighted more heavily, making it more suitable for AACE patients, whose primary complaints of binocular diplopia are mainly from straight-ahead distant or near reading positions. To the best of our knowledge, this is the first study to propose the diplopia quantification score as a adjunct indicator and emphasize the symptom-oriented pathway for the intervention in AACE patients with symptom-sign dissociation, stereopsis-diplopia paradox, and distance-near disparities.

A key observation from our study is the dissociation between symptom severity and objective signs when diplopia scoring was incorporated into the standard evaluation pathway for AACE. At baseline, we found no significant correlation between diplopia scores and deviation angles at either near or distance fixation. Moreover, a substantial proportion of patients (20.57% at distance) presented with micro-deviation (≤ 10 PD) but reported at least moderately severe diplopia, underscoring that the magnitude of strabismus alone cannot reliably predict the patient's symptomatic burden. This discordance between motor alignment and perceptual symptoms may be attributable to vergence dysfunction(13, 20) that persists even after deviation correction. In both scenarios, relying solely on objective measures may lead to underestimation of disease impact and delayed or inadequate intervention. Our results support the inclusion of patient-reported diplopia scoring as an integral component of the clinical evaluation framework for AACE.

Another clinically relevant finding pertains to the relationship between stereopsis and diplopia when diplopia scoring was incorporated into the evaluation pathway of binocular vision for AACE. We observed that a considerable proportion of patients with preserved qualitative stereopsis (99.06% at distance) still experienced prominent diplopia. Among patients with successful alignment (≤ 10 PD) and recovered stereopsis, a notable fraction (up to 25% at distance) continued to report clinically meaningful diplopia, emphasizing that stereopsis recovery and diplopia resolution are not synonymous. This paradox suggests that stereopsis, often interpreted as a marker of binocular function integrity, may instead reflect a robust fusional compensatory mechanism that, when maintained, inadvertently exacerbates the perceptual conflict underlying diplopia. That is, the brain's attempt to fuse disparate retinal images may sustain both stereoscopic depth perception and the disturbing sensation of double vision. The preservation of stereopsis in the presence of diplopia may represent an active, effortful compensatory process rather than a sign of stable binocularity(21). This interpretation challenges the conventional assumption that stereopsis restoration equates to functional success and implies that therapeutic strategies should address diverse perceptual consequences of misalignment.

Our longitudinal analysis of diplopia resolution rates further highlights the disparity between near and distance viewing conditions. While near diplopia resolved in over 95% of patients across all follow-up time points, distance diplopia resolution showed a progressive decline from 93.89% at 1 month to 71.59% at 6 months. This disparity may be attributable to the greater demands on fusional vergence(13) and the larger retinal disparity signals encountered at distance, where even small residual deviations become perceptually significant. This observation aligns with the clinical feature that AACE patients typically present with greater esodeviation at distance than at near(22), a pattern that may predispose them to more persistent distance diplopia.

Interestingly, among patients who lacked preoperative stereopsis but achieved postoperative alignment within 10 PD, the symptom improvement rate of binocular vision defined by diplopia resolution was consistently and significantly higher than that defined by stereopsis recovery, across both near and distance fixations. This finding reinforces that diplopia resolution is a more sensitive and patient-centric indicator of functional improvement than stereopsis alone, particularly in the early postoperative period when fusion may not yet be fully re-established. From a clinical standpoint, our findings advocate for a paradigm shift in evaluating binocular vision for AACE management. The success of intervention has traditionally been defined by motor alignment and stereopsis recovery(8, 9). However, our data demonstrate that these endpoints do not fully capture the patient's symptomatic experience. The inclusion of a validated diplopia quantification tool offers a practical and reproducible means to incorporate the patient's perspective into routine care. It enables clinicians to identify patients with severe symptoms despite mild signs, to monitor dynamic changes in symptom severity over time, and to set individualized treatment goals that prioritize functional improvement over arbitrary alignment thresholds.

There were several limitations in this study. First, although a small number of patients were lost to follow-up, a diplopia questionnaire interview was conducted via telephone for those who did not visit the clinic. The loss rates did not significantly affect the interpretation of the long-term results for diplopia scores. Second, the diplopia questionnaire was initially designed for a broad spectrum of strabismus patients, rather than being specifically tailored to AACE patients. Nevertheless, the scoring algorithm was broadly generalizable, addressing the gaze positions where AACE patients would experience diplopia from reading and straight-ahead distance gaze positions. Third, the relationship between BTX-A dose and efficacy is still under investigation although there was no significant difference in the mean dosage of BTX-A between the success and failure groups(23). Currently, the dose was based on physician preference without available standardized dosing guidelines for BTX-A(24). The rate of successful outcomes was reported to be the highest in a small angle of deviation group with 2.5 IU BTX-A dose(25). In this study, 2.5 IU of BTX-A was injected into the bilateral medial rectus for AACE patients based on previous reports and experience(26, 27).

In conclusion, this study provides robust evidence that quantification of diplopia serves as an effective and clinically meaningful adjunct indicator for evaluating binocular vision in AACE treatment decision-making and post-intervention follow-up. The dissociation between symptom severity and objective signs, the paradox of stereopsis in the presence of diplopia, and the differential outcomes between near and distance viewing collectively underscore the need for a symptom-oriented approach. We propose incorporating diplopia scoring into the standard evaluation pathway of binocular vision for AACE. This adjustment will complement traditional evaluation metrics, and help achieve a more holistic, patient-centered assessment of therapeutic outcomes for AACE patients.

Declarations

Ethics statement Ethics approval and consent to participate

The study approval was obtained from the Institutional Review Board of Beijing Tongren Hospital, Capital Medical University (TREC2022-KY020), and all procedures and data collection were conducted in compliance with the tenets of the Declaration of Helsinki. Written informed consent was obtained from the patients or guardians.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JIE HAO: Conceptualization, Funding acquisition, Writing – original draft, Writing – review and editing, Methodology, Investigation; **KAI CAO**: Conceptualization, Methodology, Formal analysis, Writing – review and editing; **JIAYU CHEN**: Data curation, Investigation; **MAYINUER YUSUFU**: Writing – review and editing; **JING FU**: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review and editing. All authors reviewed the manuscript.

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Figures

Diplopia, Quality of Life Scores, and Deviation Angle Over Time

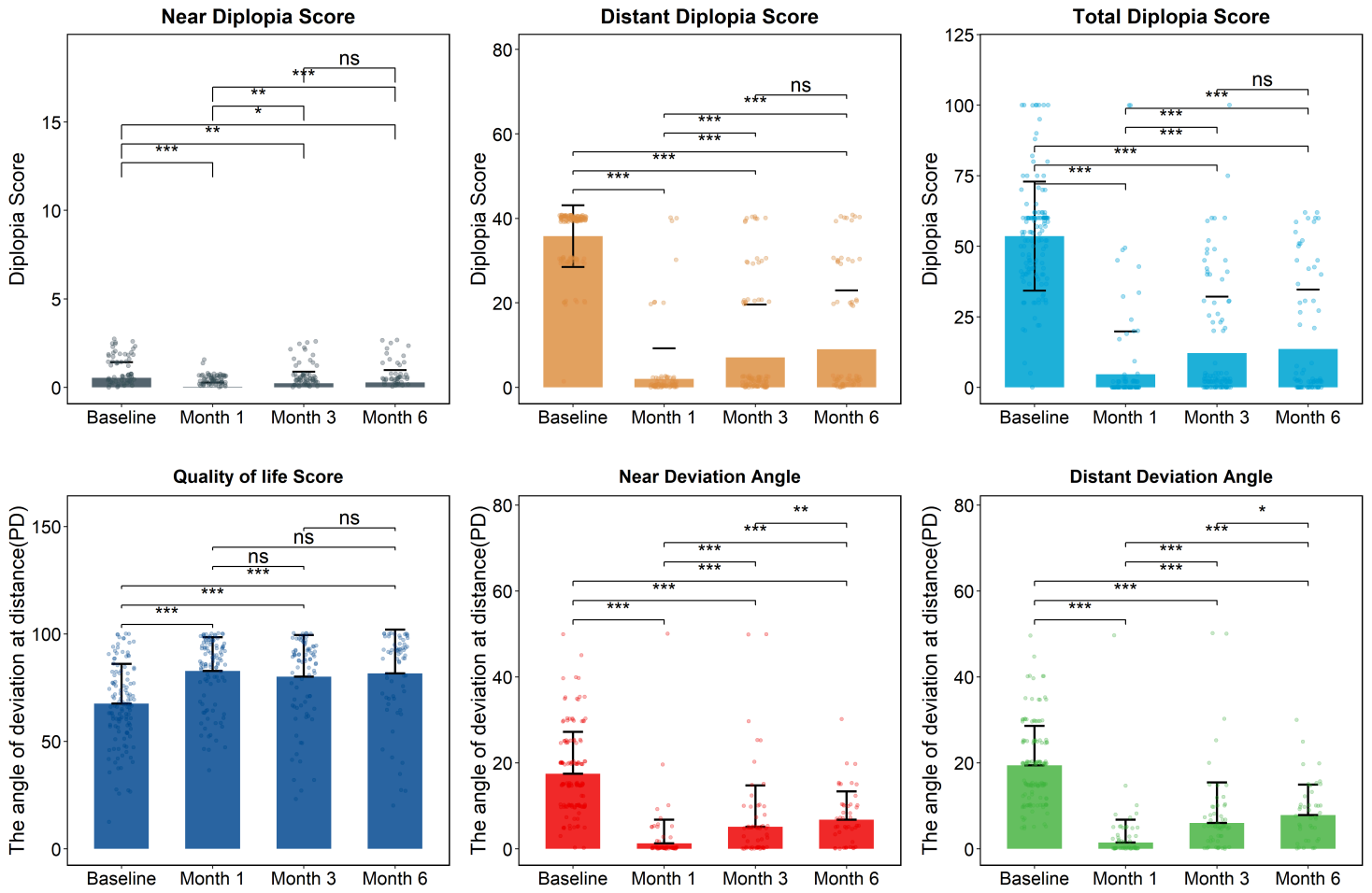


Figure 1

The diplopia quantification scores, angles of deviation, and quality of life scores at baseline and at each postoperative follow-up time point

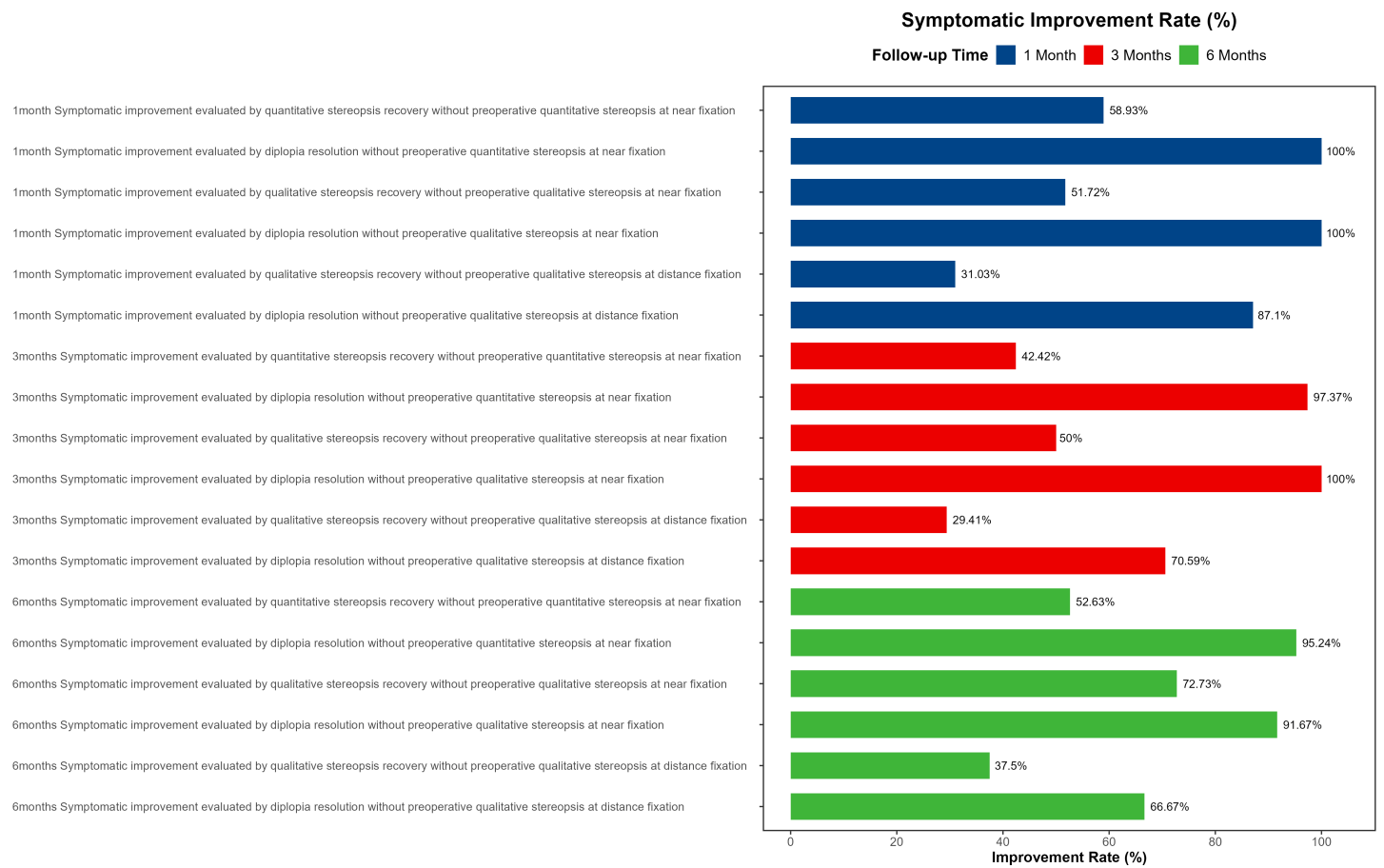


Figure 2

For AACE patients who lacked preoperative stereopsis and achieved a postoperative deviation angle within 10PD, symptomatic improvement rate of binocular vision was evaluated through two distinct functional endpoints: stereopsis recovery and diplopia resolution.