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Comparative efficacy of botulinum toxin injection versus extraocular muscle surgery in acute acquired comitant esotropia

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肉毒杆菌毒素注射与眼外肌手术治疗急性共同性内斜视的疗效对比

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摘要

目的:探讨A型肉毒杆菌毒素(BTXA)注射与斜视手术治疗急性共同性内斜视(AACE)的疗效差异。

方法:回顾性分析2019年1月至2023年9月南通市第一人民医院收治的AACE病例资料。根据治疗方式将患者分为手术组与BTXA注射组,并按术前斜视度[>35棱镜度(PD)与≤35 PD]和年龄(≥18岁成人组与<18岁青少年组)进行分层,采集患者基线特征,记录治疗前后多个时间点的斜视度,评估立体视觉功能。通过亚组疗效对比系统评估不同治疗方案的临床价值。

结果:共纳入43例AACE患者。末次随访时,手术组与注射组斜视度均较治疗前显著降低($P<0.001$)。两组在斜视治愈率与立体视觉恢复率方面存在显著差异($P<0.05$)。对于斜视度>35 PD患者,手术后斜视度控制、成功率及立体视觉恢复方面均优于注射治疗($P<0.05$);在≥18岁患者中,手术在斜视矫正、成功率提升和立体视觉重建方面同样更具优势($P<0.05$)。

结论:BTXA注射与斜视手术对AACE均具有治疗价值。手术治疗总体疗效优于BTXA注射,尤其适用于斜视度>35 PD及年龄≥18岁的患者;对于斜视度≤35 PD或未成年患者,BTXA注射仍可作为可行的治疗选择。

关键词:A型肉毒毒素;急性获得性内斜视;眼外肌手术

Abstract

• AIM: To investigate the therapeutic effects of botulinum toxin A (BTXA) injection versus strabismus surgery in the treatment of acute acquired comitant esotropia (AACE).

• METHODS: Patient records of AACE cases treated at First People's Hospital of Nantong from January 2019 to September 2023 were retrospectively analyzed in this study. Patients were categorized into either strabismus surgery or BTXA injection groups based on treatment modality. Further stratification was performed according to preoperative deviation angles [>35 prism diopters (PD) *vs* ≤35 PD] and age (≥18 years adult group *vs* <18 years adolescent group). The baseline patient characteristics were collected, deviation angles at multiple timepoints before and after treatment were measured, and stereopsis test results were documented. Through comparative analysis of therapeutic outcomes across subgroups, we systematically evaluated the efficacy of different treatment approaches.

• RESULTS: A total of 43 AACE patients were included. At the final follow-up, both the surgery and BTXA injection groups showed a statistically significant decrease in deviation angle compared to pretreatment measurements ($P<0.001$). Significant differences were noted between the two groups in terms of the cure rate of strabismus and the recovery rate of stereopsis ($P<0.05$). For patients with deviations >35 PD, surgery yielded significantly better outcomes than injection therapy in postoperative angle, success rate, and stereopsis recovery ($P<0.05$). Similarly, in patients aged ≥18 years, surgical treatment was superior to injections in reducing strabismus angle, improving success rates, and restoring stereopsis ($P<0.05$).

• CONCLUSION: Both BTXA injection and strabismus surgery demonstrate therapeutic efficacy in AACE. Surgical treatment demonstrated superior efficacy compared to BTXA injection therapy, particularly in patients with deviations > 35 PD and those aged ≥ 18 years. For patients with angles ≤35 PD or under 18 years, BTXA injection remains a viable treatment option.

• KEYWORDS: botulinum toxin A; acute acquired esotropia; extraocular muscle surgery
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INTRODUCTION

Acute acquired comitant esotropia (AACE) is a relatively rare but clinically important strabismus variant most prevalent in adolescents and young adults, characterized by acute onset of comitant esotropia with gaze-independent deviation angles[1]. In 1958, Burian and Miller[2] proposed a classification system for AACE, dividing it into three distinct subtypes: type I (Swan's type), primarily affects infants or young children, with esotropia resulting from an imbalance in the binocular fusion mechanism due to single-eye vision loss; type II (Franceschetti's type), which presents as acute onset large-angle esotropia, possibly related to physical fatigue or psychological stress; and type III (Bielschowsky type), strongly associated with myopia of varying severity.

The widespread adoption of digital screen-based devices has contributed to a progressive increase in the global burden of myopia. Current epidemiological projections suggest that 39.80% of the world's population may develop myopia by 2050[3]. Correspondingly, the prevalence of type III AACE is also increasing annually[4]. Particularly among adolescents, the frequent use of electronic devices has raised concerns about their association with acute-onset esotropia. Prolonged near work using electronic devices can increase the accommodative load on the extraocular muscles and lead to visual fatigue, which may contribute to fusion dysfunction[5]. AACE typically does not resolve on its own, and current treatments mainly include glasses correction, botulinum toxin A (BTXA) injections, or surgical intervention[6]. Prismatic treatment, when applied in a step-by-step manner, has shown positive effects on improving movement and binocular function in AACE patients with deviation angles not exceeding 25 prism diopters (PD). However, it has a long treatment duration and a significant impact on daily activities, especially for patients with severe conditions and poor cooperation, making conservative treatment less clinically beneficial[7].

BTXA and surgical treatments each have unique advantages. BTXA treatment offers advantages over surgery, as it is simpler, is less invasive, allows for quicker recovery, and effectively alleviates symptoms with fewer side effects[8]. Surgical treatment, on the other hand, can provide more lasting effects in certain cases, avoiding the side effects and limitations associated with long-term dependence on medication[9]. Although there have been numerous comparative studies on BTXA versus surgical treatment, no definitive conclusions have been reached due to differences in study design, efficacy evaluation criteria, and other factors[10-11]. The standard treatment approach for adults with large-angle strabismus is primarily surgical intervention. Nevertheless, some patients choose BTXA injection therapy as an alternative, primarily due to concerns regarding the risks associated with general anesthesia or potential postoperative scarring. While previous studies have thoroughly evaluated the efficacy of BTXA injections in small-angle AACE, research on minimally invasive treatment for large-angle AACE remains limited. In this study, we retrospectively analyzed clinical data from AACE patients treated at our institution to compare the therapeutic efficacy of surgical correction versus BTXA chemodenervation. Furthermore, the impact of preoperative deviation magnitude and patient age on BTXA treatment outcomes was evaluated.

SUBJECTS AND METHODS

Ethical Approval This retrospective cohort study adhered to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of First People's Hospital of Nantong (No. 2025KT092). Informed consent was obtained from all enrolled patients.

Subjects A comprehensive review was conducted on patients who underwent either rectus muscle surgery or botulinum toxin injection at First People's Hospital of Nantong between January 2019 and September 2023. After applying inclusion/exclusion criteria, 43 participants qualified for the study.

Inclusion and Exclusion Criteria The inclusion criteria were as follows: 1) sudden-onset diplopia diagnosed as AACE; 2) history of either botulinum toxin treatment or corrective strabismus surgery; 3) corrected visual acuity (VA) of the single eye is ≥1.0 with no abnormalities detected on slit lamp or fundoscopic examination.

The exclusion criteria were as follows: 1) amblyopia, nystagmus and other eye diseases; 2) other strabismus such as congenital esotropia, refractive accommodative esotropia and partial accommodative esotropia; 3) history of ocular surgery (excluding strabismus procedures) or ocular trauma; 4) had intracranial or neurological disorders; 5) had a follow-up duration of less than 6 mo or were lost to follow-up; 6) underwent additional surgery or botulinum toxin injection within 6 mo after treatment.

Methods Preoperative and postoperative evaluations were performed by an independent ophthalmologist who was not involved in the treatment procedures, ensuring that the assessor remained blinded to the patient's allocation (BTXA or surgery). All BTXA injections were administered solely by a senior ophthalmologist (Cao) to maintain procedural consistency, while the strabismus surgeries were jointly

completed by two other attending physicians to guarantee surgical safety. The baseline data collected included sex, age, and disease onset time. Binocular refraction was recorded, and spherical equivalent values were calculated. Alternate prism cover testing was used to quantify strabismus angle at pretreatment baseline and posttreatment intervals (1 wk, 1, 6 mo and the final follow-up).

Preoperative examination All participants received comprehensive ophthalmic assessments: best-corrected visual acuity, intraocular pressure measurement, slit-lamp evaluation of the anterior segment, fundus examination, ocular motility testing and binocular spherical equivalent calculation. Additionally, cranial MRI was performed to rule out neurological pathologies. Ocular misalignment was assessed at near (33 cm) and far (6 m) distances using the Hirschberg test and prism cover test. Stereoacuity was measured using both the synoptophore and Titmus stereotests. A positive stereopsis result was defined as the ability to identify the stereoscopic pattern on the synoptophore or a Titmus stereotest result of ≤100".

Treatment methods General anesthesia or local anesthesia was selected for surgery on the basis of the patient's age and cooperation. BTXA injection was performed by a single surgeon (Cao) using the following standardized technique: A mini-Parks incision was made in the inferonasal bulbar conjunctiva, followed by careful dissection of the intermuscular septum while preserving the muscle sheath integrity. BTXA (Hengli, 100 U/vial, China) was diluted in normal saline to the desired concentration, and 0.1 mL of the solution was injected into the muscle belly using a 30 G needle. The injection dosage was selected according to our prior clinical experience: 2.5 U for deviations ≤20 PD, 3-4.5 U for 21-40 PD, 5-6.5 U for 41-60 PD, and 7-8.5 U for deviations >60 PD.

The strabismus surgery was performed by two attending physicians under general or local anesthesia, with the surgical approach determined based on the angle of deviation: unilateral medial rectus recession was used for cases with a deviation angle ≤ 30 PD, while medial rectus recession combined with lateral rectus resection was chosen for those with a deviation angle >30 PD. For cases with a deviation angle ≥ 80 PD, bilateral medial rectus recession supplemented with lateral rectus resection was performed.

Primary outcome measures Follow-up comparisons were made after treatment to assess the strabismus angle and stereopsis function following botulinum toxin injection and strabismus surgery. Treatment efficacy was quantified using standardized success criteria, where successful outcome was operationally defined as manifest horizontal deviation <8 PD, while treatment failure was characterized by residual or recurrent deviation ≥8 PD.

Statistical Analysis All statistical analyses were conducted using IBM SPSS Statistics (version 26.0; IBM Corp.). Normality of continuous variables was verified using the Shapiro-Wilk test. Normally distributed data were presented as mean±standard deviation, while non-normally distributed data were expressed as median (interquartile range). Categorical variables were described as percentages (%). For normally distributed continuous variables, intergroup comparisons were performed using independent samples t-tests. Nonparametric data were analyzed with Mann-Whitney U tests, with subsequent Bonferroni correction for multiple pairwise comparisons. Intergroup comparisons of success rates and positive stereopsis rates were analyzed using Fisher's exact test. A two-tailed P-value <0.05 was considered statistically significant.

RESULTS

Clinical Characteristics of Acute Acquired Concomitant Esotropia During the study period, 43 patients, including 23 males and 20 females, were diagnosed with AACE at our hospital. Follow-up data beyond 12 mo were unavailable for 2 patients (5% of the cohort). Participant characteristics are presented in Table 1. The baseline data analysis of this study revealed that the patient population predominantly consisted of young adults and older children, with a disease duration of approximately one year. Notably, 79% of the cases presented with myopia, and there was no significant difference in refractive error between the left and right eyes. The degree of hyperopia was significantly greater than that of myopia. It is worth emphasizing that only 14% of enrolled patients demonstrated positive stereopsis function.

Comparison of Baseline Characteristics between the Injection and Surgical Groups The injection group included 20 patients with balanced gender distribution (10 males, 10 females), while the surgical group comprised 23 patients (13 males, 10 females). The two groups demonstrated comparable demographic characteristics and similar follow-up durations. Analysis revealed that the mean disease duration was significantly longer in the surgical group (P=0.001). No other baseline parameters showed statistically significant intergroup differences (all P>0.05). Complete baseline characteristics are summarized in Table 2.

Comparative Efficacy of Injection versus Surgical Therapy at Pre- and Post-treatment Time Points We compared the preoperative and postoperative (1 wk, 1, 6 mo, and the final follow-up) deviation angles between the surgical and injection groups (Table 3). No statistically significant differences were observed between groups for either distance or near deviation angles, although the surgical group showed numerically higher values for both parameters (P>0.05). Both interventions demonstrated significant reduction from baseline at all postoperative timepoints (P<0.001), demonstrating the excellent therapeutic efficacy of both procedures for AACE. Further postoperative analysis revealed that the surgical group exhibited significantly smaller deviation angles than the injection group at 1 wk, 1 mo, and the final follow-up (P<0.05), indicating more stable therapeutic outcomes in the surgical group during the follow-up period.

Table 1 Clinical characteristics of acute acquired comitant esotropia patients

Characteristics	Values
Number of patients(n)	43
Gender (male/female)	23/20
Age at onset ($\bar{x}\pm s$, years)	25.07±13.22
Duration of symptoms ($\bar{x}\pm s$, months)	13.79±5.15
Follow-up time ($\bar{x}\pm s$, months)	16.07±3.46
Refractive errors,(n, %)	38 (88%)
Emmetropia (n, %)	5 (12%)
Myopia (n, %)	34 (79%)
Hypermetropia (n, %)	4 (9%)
Astigmatism (n, %)	28 (65%)
Spherical equivalent ($\bar{x}\pm s$, D)	
Right	-2.62±2.35
Left	-2.54±2.21
The angle of esotropia deviation pre-injection ($\bar{x}\pm s$, PD)	
Distance (6 m)	50.93±17.12
Near (33 cm)	40.00±16.15
Stereoacuity pre-injection (n, %)	
Stereopsis (+)	6/43 (14%)
Stereopsis (-)	37/43 (86%)

Table 2 Comparison of baseline characteristics between the injection and surgical group

Characteristics	Injection group (n=20)	Surgical group (n=23)	t	P
Age ($\bar{x}\pm s$, years)	27.50±13.93	22.96±12.50	1.127	0.266[a]
Gender (male/female)	10/10	13/10	-	0.764[b]
Duration of symptoms ($\bar{x}\pm s$, months)	11.20±4.05	16.04±5.00	-3.455	0.001[a]
Right spherical equivalent ($\bar{x}\pm s$, D)	-2.90±2.00	-2.37±2.64	-0.733	0.467[a]
Left spherical equivalent ($\bar{x}\pm s$, D)	-2.80±1.70	-2.32±2.59	-0.714	0.479[a]
Follow-up time ($\bar{x}\pm s$, months)	16.00±2.87	16.14±3.97	-0.127	0.899[a]
Stereopsis (+)(n, %)	4 (20%)	2 (9%)	-	0.393[b]

[a]independent samples t-test; [b]Fisher's exact test.

Table 3 Comparison of deviation angles at different follow-up periods between surgery group and injection group $\bar{x}\pm s$

Time points	Deviation angle (PD)		t	P
	Injection group (n=20)	Surgical group (n=23)		
Pre-injection				
6 m	47.75±16.58	53.70±17.47	-1.140	0.261
33 cm	37.00±15.25	42.61±16.79	-1.140	0.261
1 week				
6 m	9.55±4.20	2.04±2.31	7.117	<0.001
33 cm	5.95±3.27	0.30±2.40	6.510	<0.001
1 month				
6 m	4.05±1.91	2.22±1.86	3.189	0.003
33 cm	2.60±1.88	1.43±1.47	2.281	0.028
6 months				
6 m	7.35±3.44	5.91±2.11	1.623	0.115
33 cm	4.60±3.98	3.30±2.57	1.248	0.221
Endpoint				
6 m	12.74±8.11	6.95±2.94	2.946	0.007
33 cm	9.00±6.33	4.27±2.12	3.107	0.005

The P value was calculated using independent samples t-test.

We compared the positive rates and success rates of stereopsis function at the final follow - up. The surgical group demonstrated a significantly higher positive rate of near stereopsis compared to the injection group ($P < 0.05$). Similarly, both the distance and near success rates were significantly higher in the surgical group than in the BTXA

injection group ($P<0.05$), confirming the superior efficacy of surgical intervention. Complications were analyzed for all affected patients, with no statistically significant difference in incidence rates between the two groups. In the botulinum toxin group, 1 case (1/20, 5%) of transient ptosis was observed, all of which completely resolved during follow-up. Notably, the surgical group experienced no severe complications such as consecutive exotropia, muscle loss/slippage, or postoperative infections (Table 4).

Comparative Efficacy in Patients with >35 PD versus ≤35 PD Deviations The study categorized patients into two groups: those with deviations >35 PD and those with ≤35 PD (Table 5). In patients with >35 PD deviations, no significant difference was observed in preoperative near and distance deviation angles between injection therapy and surgical treatment ($P>0.05$). However, final follow-up demonstrated significantly smaller residual deviations, higher success rates, and better stereoacuity outcomes with surgery ($P<0.05$). For ≤35 PD deviations, both treatments showed comparable outcomes in deviation correction, success rates, and stereoacuity recovery ($P>0.05$). These findings suggest surgical intervention should be prioritized for large-angle strabismus.

Comparative Treatment Outcomes between Adult and Young Patient Groups Patients were stratified into adult (≥18 years) and pediatric/adolescent (<18 years) subgroups (Table 6), with no significant difference in preoperative deviation angles between the two groups ($P>0.05$). Final follow-up data revealed that the adult injection group had significantly larger residual deviations than the surgical group, while the surgical group demonstrated superior outcomes in both stereopsis success and recovery rates ($P<0.05$), indicating better overall efficacy of surgical treatment for adult patients. However, in the pediatric/adolescent subgroup, no significant difference in efficacy was observed between surgical and injection treatments ($P>0.05$). This lack of significance may be attributed to the relatively small sample size in the younger subgroup, potentially limiting the generalizability and reliability of these specific findings.

DISCUSSION

In recent years, the increasing prevalence of AACE has garnered increasing attention in clinical and related research fields. As cases accumulate and studies deepen, our understanding of its pathogenesis, diagnostic methods, and treatment approaches has been continuously enriched and refined. This study focused on the clinical characteristics and treatment methods of AACE, observing the effects of BTXA injection and strabismus surgery and comparing the treatment efficacy among patients with large and small deviation angles, as well as different age groups.

The exact pathogenesis of AACE remains elusive, though potential risk factors may include excessive near-work, abnormal vergence/accommodation, vergence-divergence imbalance, extraocular muscle alterations, and neurological abnormalities[12]. Analysis of the baseline data in our study revealed that most patients were young adults and older

Table 4 Comparison of success rates and stereoacuity recovery between surgical and injection groups post-treatment

(*n*, %)

Groups	Stereoscopic vision at the endpoint		Success rate at the endpoint		Complications
	6 m	33 cm	6 m	33 cm	
Injection group	7/19 (37%)	9/19 (47%)	9/19 (47%)	11/19 (58%)	1/20 (5%)
Surgical group	14/22 (64%)	19/22 (86%)	19/22 (86%)	22/22 (100%)	0/23 (0%)
P	0.121	0.017	0.017	0.001	0.470

The *P* value was calculated using Fisher's exact test.

Table 5 Comparative treatment outcomes in patients with >35 PD *vs* ≤35 PD deviations in the two groups

PD	Injection	Surgery	*t*	*P*
>35 PD	(*n*=12)	(*n*=16)		
Pre-treatment angle of distance deviation ($\bar{x}\pm s$,6 m)	58.75±11.10	63.44±10.12	−1.164	0.255[a]
Pre-treatment angle of near deviation ($\bar{x}\pm s$,33 cm)	47.92±8.38	51.88±10.31	−1.086	0.287[a]
Distance angle of deviation at final follow-up ($\bar{x}\pm s$,6 m)	15.27±8.48	6.88±2.60	3.185	0.008[a]
Near deviation angle at final follow-up($\bar{x}\pm s$,33 cm)	11.00±6.53	4.94±1.65	3.015	0.012[a]
Success rate at the endpoint (*n*, %)	4/11 (36%)	16/16 (100%)	-	<0.001[b]
Stereoscopic vision at the endpoint of follow-up (*n*, %)	4/11 (36%)	15/16 (94%)	-	0.002[b]
≤35 PD	(*n*=8)	(*n*=7)		
Pre-treatment angle of distance deviation ($\bar{x}\pm s$,6 m)	31.25±5.83	31.43±5.56	−0.060	0.953[a]
Pre-treatment angle of near deviation ($\bar{x}\pm s$,33 cm)	20.63±3.20	21.43±3.95	−0.435	0.671[a]
Distance angle of deviation at final follow-up ($\bar{x}\pm s$,6 m)	9.25±6.52	7.17±3.97	0.689	0.504[a]
Near deviation angle at final follow-up ($\bar{x}\pm s$,33 cm)	6.25±5.23	2.50±2.35	1.625	0.130[a]
Success rate at the endpoint (*n*, %)	7/8 (88%)	6/6 (100%)	-	1[b]
Stereoscopic vision at the endpoint of follow-up (*n*, %)	5/8 (63%)	4/6 (67%)	-	1[b]

PD: Prism diopters. [a]independent samples *t*-test. [b]Fisher's exact test.

Table 6 Comparison of therapeutic outcomes between surgical and injection treatments in adult versus pediatric/adolescent patient groups

Age	Injection	Surgery	t	P
≥18 years	(n=13)	(n=14)		
Pre-treatment angle of distance deviation ($\bar{x}\pm s$,6 m)	51.54±18.30	51.43±15.12	0.017	0.987[a]
Pre-treatment angle of near deviation ($\bar{x}\pm s$,33 cm)	39.23±16.56	40.93±14.27	-0.286	0.777[a]
Distance angle of deviation at final follow-up ($\bar{x}\pm s$,6 m)	13.85±9.14	6.85±2.91	2.632	0.019[a]
Near deviation angle at final follow-up($\bar{x}\pm s$,33 cm)	10.15±6.74	4.62±2.22	2.813	0.013[a]
Success rate at the endpoint (n, %)	7/13 (54%)	13/13 (100%)	-	0.015[b]
Stereoscopic vision at the endpoint of follow-up (n, %)	6/13 (46%)	12/13 (92%)	-	0.030[b]
<18 years	(n=7)	(n=9)		
Pre-treatment angle of distance deviation ($\bar{x}\pm s$,6 m)	40.71±10.58	57.22±21.08	-2.042	0.063[a]
Pre-treatment angle of near deviation ($\bar{x}\pm s$,33 cm)	32.86±12.54	45.22±20.78	-1.385	0.188[a]
Distance angle of deviation at final follow-up ($\bar{x}\pm s$,6 m)	10.33±5.13	7.11±3.14	1.520	0.152[a]
Near deviation angle at final follow-up($\bar{x}\pm s$,33 cm)	6.50±4.93	3.78±1.99	1.510	0.156[a]
Success rate at the endpoint (n, %)	4/6 (67%)	9/9 (100%)	-	0.143[b]
Stereoscopic vision at the endpoint of follow-up (n, %)	3/6 (50%)	7/9 (78%)	-	0.329[b]

[a]independent samples t-test. [b]Fisher's exact test.

children, with the majority being myopic. Myopia is a significant characteristic of type III AACE, and this condition can develop regardless of whether refractive errors are corrected or overcorrected[13]. Significant differences were observed between distance and near deviation angles among the enrolled patients, likely attributable to increased convergence demands at closer viewing distances. This heightened medial rectus muscle tension disrupted convergence - divergence balance, exacerbating esotropia. Meanwhile, the imbalance in the accommodation-convergence system can also disrupt dynamic stereopsis, resulting in a low positive rate of stereoscopic vision in patients.

BTXA, a neurotoxin blocking neuromuscular acetylcholine release, induces temporary muscle paralysis[14]. The effects of BTXA typically last for several months, sparing patients from surgical complications and prolonging recovery periods. For pediatric patients, it shortens the duration of general anesthesia. Studies have shown that BTXA injections are more effective for children with a baseline esotropia angle ≤60 PD and a disease duration of less than 24 mo[15-17]. BTXA offers distinct advantages in treating acute comitant esotropia, such as being combined with recession surgery for enhanced outcomes. It also serves as maintenance therapy for patients with recurrent strabismus after multiple surgeries, improving their quality of life[18]. Consequently, many patients, particularly children and adolescents, tend to prefer BTXA as an initial treatment option. However, some researchers believe that the effects of BTXA are temporary and that it requires periodic injections to maintain efficacy. Repeated injections may lead to muscle resistance or reduced drug effectiveness, necessitating surgical intervention for long-term treatment. For example, Yu *et al*[19] found in a two-year follow-up that surgery provided more stable outcomes for large-angle esotropia than BTXA injections. Cai *et al*[20] studied 44 patients who underwent traditional strabismus surgery, reporting complete resolution of diplopia without recurrence during follow-up. Given the differences in efficacy between these approaches, we compared the follow-up results between surgical and BTXA injection groups.

The results of this study demonstrated that the mean disease duration in the surgical group was significantly longer than that in the injection group. This difference reflects distinct clinical indications for the two treatments: surgery is primarily employed for permanent correction of stable deviations, whereas BTXA is more suitable for short-term disease management. However, no statistically significant differences were observed between the two groups regarding gender, age, refractive status, or stereoacuity positive rates. Comparison of ocular deviation angles across different follow-up periods showed reductions in deviation angles and improvements in diplopia symptoms in both groups. These findings confirm the therapeutic efficacy of both BTXA injection and strabismus surgery in the treatment of AACE. However, surprisingly, the smaller magnitude of change observed in the injection group compared to the surgery group during the 1-6-month follow-up period may be attributed to the dynamic pharmacological properties of BTXA. The reversible paralysis induced by BTXA allows for more natural ocular position adaptation. Additionally, inherent differences in surgical techniques may also affect the stability of postoperative outcomes.

The surgical group achieved final success rates of 86% for distance and 100% for near vision, with stereopsis recovery rates reaching 64% (distance) and 86% (near). In contrast, both metrics were significantly lower in the injection group, consistent with previous findings[21], confirming the long-term stability of surgical outcomes. In this retrospective cohort analysis, we also examined the efficacy of BTXA injections in patients with different deviation angles and age groups. For AACE patients with deviation angles > 35 PD, surgical correction demonstrated superior outcomes compared to

botulinum toxin injection. Early surgical intervention is recommended to alleviate diplopia, prevent suppression, and preserve binocular function. In patients aged ≥18 years, all procedures were performed under local anesthesia, allowing real-time monitoring of ocular alignment adjustments during surgery—a factor contributing to enhanced surgical success rates. For patients with deviations ≤35 PD and age <18 years, BTXA achieved comparable efficacy to conventional strabismus surgery. BTXA may represent a minimally invasive, cost-effective, and reliable therapeutic alternative in this population.

Nevertheless, this study has certain limitations.First, potential information bias may exist during data collection. Second, when assessing stereopsis in patients with large-angle deviations, the application of Titmus testing might be limited by sensory adaptation phenomena such as suppression or abnormal retinal correspondence. In such cases, the absence of measurable binocular function does not necessarily indicate a true loss of stereopsis but may instead reflect compensatory sensory mechanisms at play. Additionally, owing to muscle tension changes caused by retinal image shifts when wearing prisms, some patients may require pretreatment prism adaptation tests to optimize correction[22]. Finally, the lack of follow-up data beyond 12 mo in approximately 5% of cases may reduce the reliability of our statistical analysis regarding binocular visual function.

In conclusion, both BTXA injections and extraocular muscle surgery are effective in treating AACE. Strabismus surgery demonstrates more stable and predictable outcomes for AACE, whereas BTXA injections can reduce surgical risks and psychological burdens, offering greater treatment flexibility for pediatric patients. Both treatments have advantages depending on disease characteristics, patient needs and expectations. This study may not capture late recurrences or long-term stability, and further research with extended follow-up periods is required to validate the durability of these therapeutic effects. Future large-scale, multicenter comparative studies will help further clarify indications and comprehensive efficacy, enabling the development of more personalized and precise treatment strategies.

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Authors' contributions: Liu TY investigated the literature and wrote the manuscript; Zhou Y visualized the results; Kuai PZ and Guo YC collected the data; Huang XB and Wang Y provided guidance; Cao X designed the research, reviewed and edited the manuscript. All authors approved the submitted version.

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