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ORIGINAL RESEARCH

The Incidence and Risk Factors for Dry Eye After Pediatric Strabismus Surgery

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ABSTRACT

Introduction: This study aimed to investigate the incidence and risk factors for dry eye after pediatric strabismus surgery.

Methods: Children aged 5–12 years who underwent strabismus surgery were included in this single-center, prospective, cohort study. The ocular surface assessments were conducted 1 day before and 1, 4, and 8 weeks after surgery. The main outcome measures were the incidence of dry eye after strabismus surgery and associated risk factors.

Results: A total of 84 eyes (48 children) that underwent strabismus surgery were included in the study. The mean age at surgery was 7.21 years. The incidence of dry eye was 47.62% at 1 week, 10.71% at 4 weeks, 0% at 8 weeks after surgery. The preoperative tear breakup time (BUT) was lower in the dry eye group than that in the non-dry eye group ($P \leq 0.01$). The univariate analysis showed that preoperative BUT was significantly associated with the incidence of dry eye after pediatric strabismus surgery (odds ratio [OR] 0.647, confidence interval [CI] 0.503–0.833, $P \leq 0.01$).

Conclusions: Dry eye commonly occurs after pediatric strabismus surgery. Tear film instability is more common than deficient aqueous tear production in patients with dry eye after surgery. Children with a low preoperative BUT are more likely to develop dry eye after strabismus surgery.

Keywords: Dry eye; Pediatric; Risk factor; Strabismus surgery; Tear breakup time

Key Summary Points

The incidence of dry eye after pediatric strabismus surgery is high but transient.

Tear film instability is more common than deficient aqueous tear production in dry eye after pediatric strabismus surgery.

The breakup time (BUT) is a sensitive parameter for evaluating the ocular surface after pediatric strabismus surgery.

Children with a low preoperative BUT are more likely to develop dry eye after strabismus surgery.

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INTRODUCTION

Strabismus, defined as a deviation from perfect ocular alignment, is a common ocular disorder in children [1, 2]. In China, the reported prevalence rate of strabismus ranges from 2.48% to 5.65% among children [3–5]. Strabismus commonly leads to amblyopia and affects binocular vision and stereopsis [6]. Strabismus even affects psychosocial development and quality of life [7]. Strabismus surgery is performed to reconstruct the normal structure and restore function, resulting in restoration of ocular alignment, restoration of sensory and motor fusion, improved binocularity [6], improvement in psychosocial well-being [8], and better health-related quality of life [9]. Surgery to correct strabismus is the most common pediatric eye surgery [10].

Dry eye (DE) refers to a group of disorders of the tear film that are caused by reduced tear production or tear film instability and are associated with ocular discomfort and/or visual symptoms and inflammatory disease of the ocular surface [11]. Most recent reports show the relationship between ocular surgery and dry eye [12]. DE is one of the most frequent complaints after corneal refractive surgery and cataract surgery [13], and leads to lower patient satisfaction [14]. After successful strabismus surgery, many patients complained of ocular irritation, including foreign body sensation, burning sensation, or dryness [15]. The symptoms associated with dry eyes in children after strabismus surgery may be one of the reasons for decreased surgical quality and patient satisfaction in the clinic. Tear film instability and conjunctival sensitivity could be the causative factors of ocular irritation symptoms after lateral rectus muscle recession [16]. Although the expert consensus on DE related to ocular surgery has been published in China [17], there is a paucity of data from children. DE in children has not received enough attention due to limited ability of the children to express symptoms [18]. Therefore, little information is available concerning the incidence and risk factors for DE in children after strabismus surgery.

The purpose of the current study was to determine the incidence and risk factors for DE after pediatric strabismus surgery by evaluating baseline characteristics, surgical factors, DE symptoms, tear film stability, tear secretion, and meibomian gland changes before and after surgery.

METHODS

This single-center, prospective, cohort study was conducted in the Ophthalmology Department of the Children's Hospital of Chongqing Medical University, Chongqing, China. This study's protocol was approved by the Ethics Committee of the Children's Hospital of Chongqing Medical University (No. 2022-195) and conducted by medically qualified personnel in strict accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from either the patient's guardians or the patients themselves.

The sample size was calculated by PASS, version 11 (NCSS, LLC, Kaysville, UT, USA). According to the results of the previous studies, we assume that a change between preoperative and postoperative tear breakup time (BUT) is at least 1 s, assuming a power of 90% with a two-sided test of 5%. The estimated sample size was 46 eyes. To allow for a dropout rate of 20%, a total sample size of at least 56 eyes was recommended.

The inclusion criteria were as follows: (1) Hospitalized children aged between 5 and 12 years; (2) with esotropia, V-pattern esotropia, exotropia, V-pattern exotropia, primary or secondary inferior oblique muscle overaction (IOOA); (3) undergoing lateral rectus recession (LRc), medial rectus recession (MRc), inferior oblique recession (IOc), lateral rectus recession and inferior oblique recession (LRc + IOc), or medial rectus recession and inferior oblique recession (MRc + IOc); (4) no history of ocular surgery or trauma. The exclusion criteria included the following: (1) preoperative DE, nystagmus, infection, allergic conjunctivitis, diabetes, kidney disease, or other systemic diseases; (2) a postoperative horizontal deviation greater than 15 prism diopters (PD), or a vertical deviation greater than 5 PD; (3) presence of ocular infection or allergy during the follow-up; (4) lost to follow-up or could not complete all examinations during the follow-up period.

All the strabismus surgeries were performed under general anesthesia and by one experienced pediatric ophthalmologist (CL) under the surgical microscope. The standard surgical protocol includes the following steps. A standardized 8-mm conjunctival incision was made in the inferotemporal and/or inferonasal regions. The subconjunctival fascial tissue was dissected with blunt Westcott scissors to expose the sclera. Once the borders of the muscle have been identified, the muscle is hooked in place. Then, the ligaments and tendons were dissected back to the insertion. A recession was performed in the tunnel with a double spade needle suture (6–0 Vicryl, Ethicon). The conjunctival incision was sutured with one knot (6–0 Vicryl, Ethicon). At the end of the surgery, TobraDex ointment (tobramycin 0.3%, dexamethasone 0.1%; Alcon, USA) was applied. The postoperative regimen included 0.3% tobramycin eye drops (tobramycin 0.3%; Alcon, USA) four times a day and TobraDex ointment eye ointment once a night for 1 week.

The baseline characteristics of the participants were recorded, including sex, age, course of disease, logarithm of the minimum angle of resolution (logMAR) of best corrected visual acuity (BCVA), intraocular pressure (IOP), the prism diopters of deviations, spherical equivalent (SE), fixation (dominant eye or nondominant eye), operative time, and the number of muscles operated on in each eye at the time of enrollment. The ocular surface assessments were as follows: dry eye score system (DESS) questionnaire, BUT, corneal fluorescein staining (CFS), tear meniscus height (TMH), and the score of meibomian gland changes (meiboscore). The prism diopters of deviations were the mean value of the prism and alternate cover test (PACT) at distance (6 m) and near (1/3 m). In children with alternate fixation, both eyes were dominant eyes. In children without alternate fixation, the squinting eye was the nondominant eye, and the contralateral eye was the dominant eye.

The DESS was used to assess the occurrence of six symptoms of dry eye, each scored as absent (= 0), sometimes (= 1), frequently (2), or always present (= 3). Ocular symptoms include itching, burning, sandy or gritty sensation, redness, blurred vision, ocular fatigue, and excessive blinking. A total score of 0–6 indicated mild symptoms, from greater than 6 to 12 indicated moderate symptoms, and from greater than 12 to 18 indicated severe symptoms of dry eye. The TMH and meiboscore were measured by noncontact infrared meibography (Keratograph 5M, OCULUS, Germany) [19]. The lower TMH was measured in tear meniscus mode. The mean of three measurements was recorded. The meiboscore was assessed as previously reported [20]. Partial or complete loss of the meibomian glands was scored for each eyelid from grade 0 (no loss of meibomian glands) through grade 3 (the lost area was more than two-thirds of the total meibomian gland area). The final score of each eye was 0–6 points, including the upper and lower eyelids. Finally, the measurement and scoring criteria of the BUT and CFS were as described in our previous study [21].

The diagnosis of DE was based on expert consensus on dry eye in China. DE was diagnosed if the child had any symptoms along with a BUT of less than or equal to 5 s or a BUT greater than 5 s and less than or equal to 10 s concomitant with positive CFS [17]. The diagnosis of meibomian gland dysfunction (MGD) was based on the suggestions by the international workshop on MGD [22]. Each patient was assessed 1 day before surgery and 1, 4, and 8 weeks after surgery.

Data were analyzed using SPSS version 18.0 software (SPSS, Inc., Chicago, IL, USA). Values for continuous variables are presented as the mean ± standard deviation. Quantitative data were compared between the groups using Student's *t* test. The categorical variables were compared with the chi-square test. Factors associated with dry eye were assessed by odds ratios (ORs) with 95% confidence intervals of logistic regression analysis. Variables with a statistical significance of $P < 0.10$ in the univariate analysis were included in the multivariate model. Statistical significance was defined as $P < 0.05$.

RESULTS

Demographics and Clinical Characteristics of Study Population

Fifty-seven consecutive children (98 eyes) who underwent strabismus surgery between January 1, 2022 and July 31, 2022 were enrolled in this study. The children were divided into the dry eye (DE) group and the non-dry eye (non-DE) group according to whether dry eye was diagnosed 1 week after strabismus surgery. During 8 weeks of follow-up, 8 children (14 eyes) were excluded from our study; 5 children (10 eyes) were excluded because of allergic conjunctivitis and 3 children (4 eyes) were lost to follow-up. Finally, 24 children (40 eyes) in the DE group and 24 children (44 eyes) in the non-DE group were eligible for final analysis (Fig. 1).

The mean age at surgery was 7.21 years. There were 15 cases of exotropia, 11 cases of V-pattern exotropia, 8 cases of esotropia, 8 cases of V-pattern esotropia, and 6 cases of primary or secondary IOOA. Thirty-six (75%) children underwent bilateral surgery, and 12 (25%) children underwent unilateral surgery. The types of surgery were LRc in 30 (35.71%) eyes, MRc in 15 (17.86%) eyes, IOc in 9 (10.71%) eyes, LRc + IOc in 18 (21.43%) eyes, and MRc + IOc in 12 (14.29%) eyes. Table 1 shows the preoperative baseline data of the children. The DESS score was 0.08 ± 0.03, and 6 children (12.5%) complained of symptoms of dry eye. The baseline BUT was 7.71 ± 0.26 s and less than 10 s in 63 (75%) eyes. Four children had positive corneal fluorescein staining before surgery. The baseline CFS was 0.05 ± 0.02. The baseline TMH was 0.17 ± 0.01. The baseline meiboscore was 0.08 ± 0.03. Seven in 84 (8.33%) eyes had a grade 1 meiboscore before surgery.

Incidence of Dry Eye After Strabismus Surgery

Based on the diagnostic criteria of the Chinese consensus, DE was diagnosed in 40 eyes (47.62%) 1 week after strabismus surgery. The incidence of DE was 10.71% (9 eyes) at 4 weeks postoperatively. No children met the diagnostic criteria for DE 8 weeks after surgery.

Comparison of Clinical Features in Children with or Without Development of Dry Eye After Strabismus Surgery

Table 2 shows the clinical features of the children with and without DE after strabismus surgery. The preoperative BUT was obviously lower

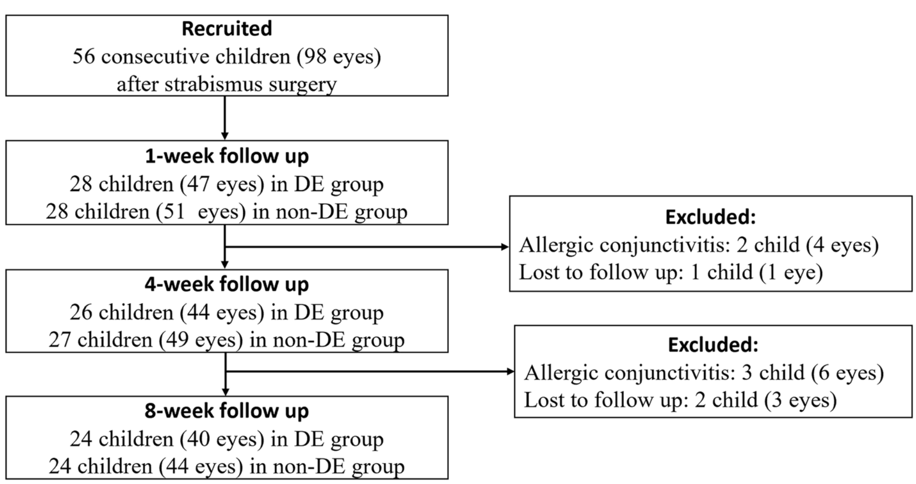

Fig. 1 Demographics and clinical characteristics of the study population

Table 1 Demographics and clinical characteristics of the study population

Parameter	Value
Age (years)	7.21 ± 0.20
Gender, male (%)	52 (61.90%)
Baseline DESS	0.08 ± 0.03
Baseline BUT	7.71 ± 0.26
Baseline CFS	0.05 ± 0.02
Baseline TMH	0.17 ± 0.01
Baseline meiboscore	0.08 ± 0.03
Laterality of surgery, *n* (%)	
Bilateral	36 (75%)
Unilateral	12 (25%)
Types of surgery, eyes (%)	84 (100%)
LRc	30 (35.71%)
LRc + IOc	18 (21.43%)
MRc	15 (17.86%)
MRc + IOc	12 (14.29%)
IOc	9 (10.71%)

DESS dry eye score system, *BUT* tear breakup time, *CFS* corneal fluorescein staining, *TMH* tear meniscus height, *LRc* lateral rectus recession, *IOc* inferior oblique recession, *MRc* medial rectus recession

in the DE group than in the non-DE group (6.71 ± 0.31 vs. 8.63 ± 0.36, $P \leq 0.01$). Other preoperative ocular surface assessments, including CFS, TMH, and meiboscore, showed no difference between the two groups. There was no difference in age, sex, BCVA, SE of refractive status, IOP, fixation (dominant or nondominant eye), course of disease, deviation PD, or operation time between the two groups.

Ocular Surface Assessment in Children with or Without Development of Dry Eye After Strabismus Surgery

In the DE group, the DESS was significantly increased at 1 and 4 weeks after surgery and returned to baseline at the 8-week follow-up. In the non-DE group, the DESS was increased at 1 week after surgery and returned to baseline at 4 weeks after surgery. The DESS increased more significantly in the DE group than in the non-DE group at 1 and 4 weeks after surgery. There was no difference in the DESS between the two groups 4 weeks after surgery. The BUT decreased significantly 1 week after surgery and returned to baseline 4 weeks after surgery in both groups. However, the BUT decreased more significantly in the DE group than in the non-DE group. There was a significant difference between the two groups at 1, 4, and 8 weeks after surgery. The CFS increased significantly 1 week after surgery and returned to baseline 4 weeks after surgery in both groups. The CFS increased more significantly in the DE group than in the non-DE group at 1 and 4 weeks after surgery. Compared with the baseline, there was no difference in TMH or meiboscore at the 1-, 4-, or 8-week follow-up in either group. There was no difference in TMH or meiboscore between the two groups at the postoperative follow-up (Table 3).

Risk Factor Analysis for Dry Eye After Strabismus Surgery

In the univariate analysis, the baseline BUT was significantly associated with the development of DE after strabismus surgery (OR 0.673, 95% CI 0.539–0.841, $P < 0.01$). Other variables considered to have a statistical significance, $P < 0.10$, in the univariate analysis included sex, alternate fixation, and BCVA in the multivariate model. Table 4 showed the multivariate logistic regression analysis for dry eye after strabismus surgery. The statistically significant factors for dry eye after strabismus surgery were baseline BUT (OR 0.647, 95% CI 0.503–0.833, $P < 0.01$), preferred fixation (OR 0.329, 95% CI 0.116–0.932, $P = 0.036$), and female sex (OR 3.084, 95% CI 1.027–9.264, $P = 0.045$).

DISCUSSION

Dry eye is a multifactorial disease of the ocular surface characterized by a loss of homeostasis of the tear film and accompanied by ocular symptoms, in which tear film instability and

Table 2 Comparison of clinical features in children with or without development of dry eye after strabismus surgery

	DED group (n = 40)	Non-DED group (n = 44)	t/χ^2	P value
Age (years)	7.06 ± 0.33	7.34 ± 0.23	0.69	0.49
Gender, male (%)	21 (52.50%)	31 (70.45%)	2.86	0.09
BCVA	0.76 ± 0.19	0.84 ± 0.19	1.91	0.07
Spherical equivalent (D)	1.24 ± 0.31	0.90 ± 0.27	0.82	0.42
IOP (mmHg)	18.08 ± 0.19	18.09 ± 0.21	0.02	0.98
Fixation				
Dominant eye	24	18	3.06	0.08
Non-dominant eye	16	26		
Duration of strabismus (months)	39.55 ± 3.43	35.20 ± 3.80	0.85	0.40
Deviation (PD)	45.63 ± 3.10	45.41 ± 2.39	0.05	0.96
Operation time (min)	20.58 ± 1.20	20.52 ± 0.87	0.04	0.97
Preoperative DESS	0.10 ± 0.05	0.05 ± 0.05	0.82	0.41
Preoperative BUT	6.71 ± 0.31	8.63 ± 0.36	4.06	0.00**
Preoperative CFS	0.08 ± 0.04	0.02 ± 0.02	1.09	0.28
Preoperative TMH	0.17 ± 0.00	0.18 ± 0.00	0.63	0.53
Preoperative meiboscore	0.10 ± 0.05	0.07 ± 0.04	0.52	0.61

BCVA best-corrected visual acuity, *IOP* intraocular pressure, *DESS* dry eye score system, *BUT* tear breakup time, *CFS* corneal fluorescein staining, *TMH* tear meniscus height

hyperosmolarity, ocular surface inflammation and damage, and neurosensory abnormalities play etiological roles [23]. Ocular surgery is one of the important risk factors for DE or exacerbation of existing DE [17]. Postoperative dry eye is also a cause of reduced visual function and compromises the results of ocular surgery [11]. Strabismus is the deviation of eye position caused by the imbalance of extraocular muscles in both eyes, which is more common in children, accounting for 72.2% of the strabismus population [24]. In recent years, a few studies have shown reports of ocular irritation symptoms and ocular surface abnormalities after strabismus surgery [15, 16, 25]. To our knowledge, there are no studies on the incidence and risk factors for DE in children after strabismus surgery. In the current study, we observed children aged 5–12 years who underwent strabismus surgery with a fornix conjunctival incision and evaluated the incidence and risk factors for postoperative DE. The incidence of DE after pediatric strabismus was 47.62% at 1 week and 10.71% at 4 weeks after surgery. All patients with DE returned to normal at the 8-week follow-up. An abnormal preoperative BUT is a significant risk factor for DE after strabismus.

In the current study, we first assessed the incidence of DE after strabismus in children. At 1 week after surgery, 47.62% of the children developed dry eye. DE after pediatric strabismus surgery was transient, appeared to decrease with time, and lasted no more than 8 weeks. There was no persistent postsurgical DE after pediatric strabismus surgery, which is usually reported after many other ocular surgical events [12]. Persistent DE was most common after refractive corneal surgery. The incidence of DE ranged from 36.36% to 41.18% at 6 months after laser

Table 3 Comparison of ocular surface assessment in children with or without development of dry eye after strabismus surgery

	DED group (n = 40)	Non-DED group (n = 44)	t	P value
DESS, baseline	0.12 ± 0.05	0.05 ± 0.05	1.14	0.26
1-week follow-up	1.30 ± 0.07[aa]	0.25 ± 0.07[a]	10.10	0.00**
4-week follow-up	0.50 ± 0.09[bb]	0.18 ± 0.06	2.85	0.01*
8-week follow-up	0.10 ± 0.05	0.09 ± 0.05	0.14	0.89
BUT, baseline	6.71 ± 0.31	8.63 ± 0.36	4.06	0.00**
1-week follow-up	4.63 ± 0.20[aa]	6.66 ± 0.31[aa]	6.62	0.00**
4-week follow-up	6.44 ± 0.31	8.25 ± 0.36	3.72	0.00**
8-week follow-up	7.36 ± 0.31	8.67 ± 0.34	2.88	0.00**
CFS, baseline	0.08 ± 0.04	0.02 ± 0.02	1.09	0.28
1-week follow-up	0.70 ± 0.07[aa]	0.27 ± 0.07[aa]	4.27	0.00**
4-week follow-up	0.20 ± 0.06	0.05 ± 0.03	2.16	0.03*
8-week follow-up	0.03 ± 0.03	0.05 ± 0.03	0.51	0.61
TMH, baseline	0.17 ± 0.01	0.18 ± 0.01	0.63	0.53
1-week follow-up	0.16 ± 0.00	0.16 ± 0.00	1.17	0.25
4-week follow-up	0.17 ± 0.01	0.18 ± 0.00	0.57	0.57
8-week follow-up	0.19 ± 0.00	0.18 ± 0.00	0.45	0.65
Meiboscore, baseline	0.10 ± 0.05	0.07 ± 0.04	0.52	0.61
1-week follow-up	0.05 ± 0.03	0.04 ± 0.03	0.10	0.61
4-week follow-up	0.05 ± 0.03	0.04 ± 0.03	0.10	0.61
8-week follow-up	0.05 ± 0.03	0.04 ± 0.03	0.10	0.61

DESS dry eye score system, *BUT* tear breakup time, *CFS* corneal fluorescein staining, *TMH* tear meniscus height
*Statistically significant ($P < 0.05$)
**Statistically significant ($P < 0.01$)
[a,b]Compared with the baseline ($P < 0.05$)
[aa,bb]Compared with the baseline ($P < 0.01$)

refractive surgery because of corneal neuropathy [26–28]. In terms of incisions for strabismus surgery, a conjunctival incision was made in surgery without causing corneal injury, avoiding the possibility of corneal neuropathy. Considering that a limbal incision is more likely to cause more severe DE symptoms and tear film instability than a fornix incision [25], a fornix conjunctival incision was made in all the surgeries performed in our study. This was one reason why DE after pediatric strabismus surgery lasted no more than 8 weeks in our study. In addition, in the preoperative setting, both high dry eye symptom scores and meibomian gland dysfunction (MGD) were determined to be risk factors for persistent DE after cataract surgery [29, 30]. In the current study, the baseline dry eye symptom score was low (0.08 ± 0.03), and only 6 children (12.5%) complained of mild symptoms of dry eye. No

Table 4 Risk factors for dry eye after strabismus surgery

Variables	With vs. without dry eye after strabismus surgery			
	Univariate OR (95% CI)	*P* value	Multivariate OR (95% CI)	*P* value
Age (per years)	0.917 (0.720, 1.168)	0.482		
Gender (female)	2.158 (0.880, 5.290)	0.093	3.084 (1.027, 9.264)	0.045*
Spherical equivalent (per D)	1.133 (0.415, 3.095)	0.807		
IOP (mmHg)	0.996 (0.718, 1.382)	0.983		
Dominant eye (yes/no)	0.433 (0.179, 1.045)	0.063	0.329 (0.116, 0.932)	0.036*
Types of strabismus				
ET and ET + IOOA	1.436 (0.269, 7.678)	0.672		
XT and XT + IOOA	1.037 (0.209, 5.146)	0.965		
Duration of strabismus (mins)	1.008 (0.990, 1.027)	0.398		
BCVA	0.108 (0.010, 1.130)	0.063	0.103 (0.006, 1.092)	0.127
Baseline DESS	1.889 (0.400, 8.918)	0.422		
Baseline BUT (s)	0.673 (0.539, 0.841)	< 0.001**	0.647 (0.503, 0.833)	0.001**
Baseline CFS	3.486 (0.348, 34.965)	0.288		
Baseline TMH (μm)	0.047 (0.000, 558.656)	0.523		
Baseline meiboscore	1.519 (0.318, 7.244)	0.600		
Surgical incision (one/two)	2.500 (0.690, 9.056)	0.163		
Operative extraocular muscle (one/two)	0.942 (0.385, 2.304)	0.896		
Surgical time (mins)	1.001 (0.939, 1.068)	0.971		
≤ 15	1.250 (0.221, 7.084)	0.801		
16–30	0.667 (0.184, 2.414)	0.537		

IOP intraocular pressure, *BCVA* best-corrected visual acuity, *ET* esotropia, *XT* exotropia, *IOOA* inferior oblique muscle overaction, *DESS* dry eye score system, *BUT* tear breakup time, *CFS* corneal fluorescein staining, *TMH* tear meniscus height, *OR* odds ratio, *CI* confidence interval
*Statistically significant ($P < 0.05$)
**Statistically significant ($P < 0.01$)

preexisting MGD was observed in children with strabismus before surgery. The age of the study population could explain the difference in preoperative MGD before surgery. The cataract surgery population is mostly adults and elderly individuals, while the current study population is children. Morphological changes, such as orifice narrowing and pouting, increased with age, and meibomian gland secretions were less easily expressed in elderly individuals [31]. There was no MGD in the pediatric population before surgery, which was another reason why there was no persistent DE after pediatric strabismus surgery.

In addition, we compared changes in DESS, BUT, and CFS before and after strabismus surgery in children with or without postoperative DE. In the DE group, the postoperative DESS increased significantly at 1 and 4 weeks and returned to baseline at the 8-week follow-up.

The postoperative BUT decreased and CFS increased significantly at 1 week and returned to baseline at 4-week follow-up. In the non-DE group, the postoperative DESS and CFS increased and BUT decreased significantly at 1 week and returned to baseline at the 4-week follow-up. Our results were partly consistent with Li and coworkers [25], who evaluated dry eye symptoms and tear film stability after strabismus surgery with a fornix incision. In their study, the dry eye symptoms scores and BUT returned to baseline at the 4-week follow-up. The main reason for the difference is that the baseline BUT (7.71 ± 0.26) was lower in our study than in theirs (12.9 ± 3.42). The difference in preoperative BUT may be partly explained by the different ages of the study populations. The mean age in our study was lower (7.21 years) than theirs (20.6 years). Gao and coworkers [32] found that inflammatory cytokines (interleukin-6 and tumor necrosis factor-α) in the tears of children with concomitant exotropia were significantly higher than those of normal subjects, but this difference was not observed in adults. Further studies are needed to clarify the mechanism of low BUT and the correlation with high inflammatory cytokines in children with strabismus. Reports from the International Dry Eye Workshop (DEWS II indicated that the two main causes of dry eyes included deficient aqueous tear production and tear film instability, which may exist independently or in combination [11, 33]. The results of this study showed that postoperative tear film instability was significantly increased in all children with strabismus, but there was no difference in preoperative and postoperative TMH between the DE and non-DE groups. TMH was the most effective predictor of aqueous tear production deficiency, and TMH measured with the Keratograph had good repeatability and reliability [34]. The sensitivity of TMH in the diagnosis of aqueous deficiency dry eye was more than 90% [35]. In the current study, there was no statistically significant difference in the TMH values between the two groups during the postoperative follow-up. These results indicated that tear film instability was more common than deficient aqueous tear production in DE after pediatric strabismus surgery.

In the present study, we demonstrated that the BUT was obviously lower in the DE group than in the non-DE group and that the preoperative baseline BUT was significantly associated with the development of DE after strabismus surgery in the univariate and multivariate analyses. Pediatric patients with mild ocular surface damage may report fewer dry eye symptoms than adult patients with similar stages of ocular surface damage [36]. According to the Chinese criteria for the diagnosis of dry eye, dry eye is not diagnosed in children with a BUT less than 10 s without dry eye symptoms. In the current study, some children had a BUT less than 10 s before surgery, but dry eye was not diagnosed because they did not have any dry eye symptoms. In clinical practice, pediatric dry eye is often overlooked because of the child's inability to participate in the assessment of subjective symptoms [37]. Therefore, the BUT is a sensitive parameter for evaluating the ocular surface after pediatric strabismus surgery.

We found that the nondominant eye was possibly another risk factor for postoperative dry eye in the multivariate logistic analysis, although it was not statistically significant in the univariate analysis. For a patient with strabismus with a strong dominance for one of the eyes, the nondominant eye showed persistent deviation and suppression [38]. The persistent deviation of the nondominant eye increased exposure to the bulbar conjunctiva region and goblet cell reduction, which may result in thinning of the lipid layer of the tear film, increased tear film instability, evaporative tear loss, and tear hyperosmolarity [39]. Therefore, nondominant eyes are more likely to develop postoperative dry eye. Interestingly, the multivariate regression analysis showed that female patients were more likely to develop DE after trabismus surgery. Several studies have shown that women are at higher risk for the development of chronic DE or severe DE symptoms after refractive surgery [40, 41]. Because of the differences in surgical methods and the age of the study population, it is unclear whether the age of children undergoing strabismus surgery has an effect on whether postoperative DE develops. Since the nondominant eye and female sex were not statistically significant in the univariate analysis and *t* test, more data are needed to prove its reliability in the future.

This study has some limitations. First, although Schirmer's test is still the most common method used to evaluate tear production, it is difficult to perform in pediatric patients because of its invasiveness. TMH was used to assess tear production in the current study. Second, we analyzed the proportion of eyes that underwent rectus and oblique muscle regression surgery, without resection or transposition surgery. Although the results from this cohort can provide useful data for this pediatric population, they may not be generalizable to all populations with strabismus. Data from larger samples and multicenter studies including all types of strabismus surgery are needed to clarify the issue. Third, the diagnostic criteria of dry eye in this study were based on the Chinese consensus; therefore, the population was only Chinese. Thus, the results are not representative of children of other races and regions. Fourth, the results only showed the incidence of DE but the mechanism of DE was not comprehensively evaluated. Further studies could be designed to assess the mechanism of DE after pediatric strabismus surgery.

CONCLUSION

Despite these limitations, in this study, we found that the incidence of dry eye in children after strabismus surgery is high but transient. A low preoperative BUT is a significant risk factor for postoperative dry eye. It should be kept in mind that the evaluation of the preoperative and postoperative tear film stability, particularly in children with a low preoperative BUT who are more likely to develop dry eyes after surgery.

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Compliance with Ethics Guidelines. This study's protocol was approved by the Ethics Committee of the Children's Hospital of Chongqing Medical University (NO. 2022-195) and conducted by medically qualified personnel strictly following the Declaration of Helsinki.

Data Availability. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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