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ORIGINAL PAPER

The difference of surgical outcomes between manifest exotropia and esotropia

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Abstract
Purpose To determine the factors that affect ocular alignment and binocular sensory functions after strabismus surgery and compare surgical outcomes between manifest exotropia (XT) and esotropia (ET).
Methods In a retrospective study, 41 XT and 17 ET patients who had undergone strabismus surgery were recruited. Information on type and duration of strabismus, age at onset of deviation and surgery, pre- and postoperative strabismus deviation angles, and binocular sensory functions including stereoacuity and macular fusion capacity was recorded.
Results In all patients, the ocular alignment and binocular sensory functions improved with time following surgery. Residue strabismus deviation angles (≦ 10 prism diopters) at postoperative 1 month determined the final successful ocular alignment. In patients with final excellent binocular sensory functions, XT group restored macular fusion capacity and stereoacuity at postoperative 1 month, but ET group regained macular fusion capacity at postoperative 1 month and then restored stereoacuity at postoperative 3 months. Though XT patients showed better pre- and postoperative stereoacuity than ET patients, patients with successful ocular alignment had an odd of 4.5 in XT group and 22.5 in ET group to achieve excellent and fair binocular sensory functions.
Conclusion Surgical correction of strabismus could improve ocular alignment and binocular sensory functions in patients with manifest strabismus, regardless of onset age, strabismus duration, or type. Postoperative 1-month status may help to predict the final motor and sensory outcomes. ET patients would benefit more final successful ocular alignment and excellent binocular sensory functions from early surgery and maintaining postoperative small deviation angle than XT patients.

Keywords Exotropia · Esotropia · Motor alignment · Stereoacuity · Macular fusion capacity · Binocular sensory function

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Introduction

Strabismus, a misalignment of the eyes, is one of the most common pediatric eye conditions with both functional and cosmetic consequences. The misalignment of the eyes can lead to a loss of binocularity and depth perception [1] and have adverse psychologic [2] and social [3–6] effects on patients [7]. Binocular sensory function, such as stereoacuity, has a functional impact on the performance of motor skills tasks [8]. Therefore, improvement of ocular alignment and binocular sensory function is the goal of surgical correction in patients with strabismus [9].

Many previous studies have reported factors that affect ocular alignment following strabismus surgery, but the results vary wildly due to the different definitions of surgical success, duration of follow-up, and strabismus type [10–19]. Several studies revealed factors influencing postoperative stereoacuity; however, macular fusion capacity or comprehensive evaluation of all known factors on binocular sensory function in a single study has not been addressed previously [7]. There is no consensus on which parameters are most important in predicting surgical outcomes, including ocular alignment and binocular sensory function.

Hence, our study aimed to (1) evaluate macular fusion capacity and stereoacuity as a determinant of binocular sensory function; (2) identify factors that affect the final motor and sensory outcomes, across follow-up time and the type of strabismus, and (3) investigate differences between concomitant manifest exotropia (XT) and esotropia (ET).

Materials and methods

We conducted a retrospective study on consecutive patients who visited Kaohsiung Chung Gung Memorial hospital with strabismus from July 2011 to September 2015. The research protocol was approved by Chung Gung Memorial Hospital Institutional Review Board (IRB) (IRB Number 105-0928C).

Patients with manifest strabismus and a previous history of intermittent type or intermittent strabismus with poor control were included in the study. The historical information of strabismus was provided by the patients, parents, or guardians. Patients were considered to have a strabismus if the deviation was intermittently manifested at either distance or near distance. Additionally, all patients were required to be able to undergo examinations including motor and binocular sensory functional tests. To obtain accurate measurements, the lower limit of age for inclusion was set at 3 years. The exclusion criteria were as follows: the follow-up time less than 6 months, paralytic or restrictive strabismus, a history of trauma or previous strabismus surgery, coexistent ocular disease, neurologic or systemic impairment, best-corrected visual acuity (BCVA) lower than 20/25 in either eye as determined by the Snellen chart, or preoperative stereoacuity $\leqq$ 40 s of arc.

Examination and data collection

All patients underwent a complete ophthalmologic examination prior to surgery. Data collected included gender, visual acuity corrected for refractive error, age at onset of strabismus, age at surgery, duration of strabismus, and the deviation angle when fixating on a near target (33 cm) at baseline and follow-ups. To reduce the effect of over-convergence for the near target, a + 3.0 diopters (D) lens was placed in front of both eyes to optimize the deviation angle. The eye alignment with the maximum angle of deviation was measured using prism and cover tests with loose prisms. The stereoacuity and macular fusion capacity were determined as part of the binocular sensory function using the Titmus stereotest (Titmus Optical Co, Petersburg, Virginia, USA) and Worth's 4-dot test [7] at a near distance (33 cm), respectively. A stereoacuity $\leqq$ 60 s of arc was defined as bifixation, while gross stereopsis was defined as 60–800 s of arc. Patients who exhibited no stereopsis and identified the wings of fly only were coded arbitrarily as 10000 and 3600 s of arc, respectively, and recorded as nil. The capacity for macular fusion was divided into two categories: good macular fusion (image of four light circles for a positive Worth's 4-dot response, W4D(+)) and no macular fusion (image of two, three, or five light circles for a negative Worth's 4-dot response, W4D(−)). The refractive errors were recorded as a spherical equivalence (spherical + 0.5 × cylinder). The difference between the refractive errors of both eyes in diopters (D) was considered as the degree of anisometropia.

Operation

All patients in the present study were advised to undergo surgery by one surgeon (H-MH) if examination or patient history indicated that the frequency or magnitude of strabismus increased or if tropia was present $> 50\%$ of the time. The types of surgery included bilateral rectus recessions or unilateral recession and resection procedures. Surgical extent was based on the maximum angle of deviation.

Surgical outcome assessment

The surgical outcomes were evaluated in motor alignment and binocular sensory functions separately. At the 6-month follow-up after surgery, successful ocular alignment was defined as the final deviation ≤ 10 prism diopters (PD). Final binocular sensory function was classified into excellent (both good macular fusion *and* bifixation), fair (either good macular fusion *or* bifixation), and poor (neither good macular fusion nor bifixation). Improvement of stereopsis was defined as the achievement of both bifixation from gross or nil stereopsis and gross stereopsis from nil.

Statistical analysis

SPSS20.0 software was used for statistical analysis. For the purpose of this analysis, the deviation angle was recorded as a continuous variable, with residue deviations after surgery opposite to original strabismus pattern denoted by negative values, and residue deviations after surgery similar to the original strabismus pattern recorded as positive values. Stereoacuity data, recorded in seconds of arc, were log-transformed. The changes between preoperative and postoperative status in ocular alignment and binocular sensory function were analyzed with repeated measures of ANOVA. The difference in variables between distinct groups graded by final outcomes was assessed using the independent t test, one-way ANOVA, Chi-square test, or repeated measures of two-way ANOVA. We considered p values of < 0.05 as statistically significant.

Results

Subject basic characteristics

A total of 58 patients (28 males) were enrolled in the study, with a mean age of onset and surgery of 5.9 ± 7.3 [median and range 3.0 (0.0–41.0)] and 15.4 ± 12.9 years [11.0 (3.0–61.0)], respectively. Forty-one patients were diagnosed with XT and 17 patients with ET. In patients with XT, the mean age of onset and surgery was 6.1 ± 7.9 [median and range 3 (0.0–30.0)] and 16.1 ± 12.6 [median and range 12 (3.0–55.0)], respectively, and the mean duration from XT onset to surgery was 9.9 ± 7.4 years [median and range 8.0 (1.0–30.0)]. In patients with ET, the mean age of onset, surgery, and duration from ET onset to surgery were 5.3 ± 5.7 [median and range 3 (0.5–24.0)], 13.5 ± 13.5 [median and range 7 (4.0–58.0)], and 8.3 ± 13.3 years [3.0 (1.0–55.0)], respectively. At enrollment, all patients had constant or poorly controlled intermittent strabismus and the mean deviation angles in the primary position were 45.9 ± 12.6 PD in XT and 38.4 ± 15.7 PD in ET patients. Preoperatively, stereoacuity was 2.9 ± 0.9 log seconds of arc in XT and 3.7 ± 0.7 log seconds of arc in ET patients; in addition, good macular fusion capacity was achieved in 17.1% ($n = 7$) of XT and 11.8% ($n = 2$) of ET patients.

Surgical outcomes

Surgical outcomes were evaluated at 1, 3, and 6 months after surgery. In patients with either XT or ET, the deviation angles decreased ($p < 0.01$) and the stereoacuity improved ($p < 0.01$) significantly at the postoperative 1, 3 and 6 months, as compared with preoperative status by repeat measure of ANOVA. In addition, significantly higher number of patients had a good macular fusion capacity at the 1-, 3-, and 6-month follow-up than pre-operation ($p < 0.01$). The rate of improvement in deviation angles, stereoacuity, and the portion of patients with good macular fusion capacity reached a peak at the 1-month follow-up and slowed over the next follow-up time points in XT patients. Similarly, in ET group, the rate of improvement in deviation angles reached a peak at the 1-month follow-up, but stereoacuity and the portion of patients with good macular fusion capacity reached a peak at the 3-month follow-up (Fig. 1).

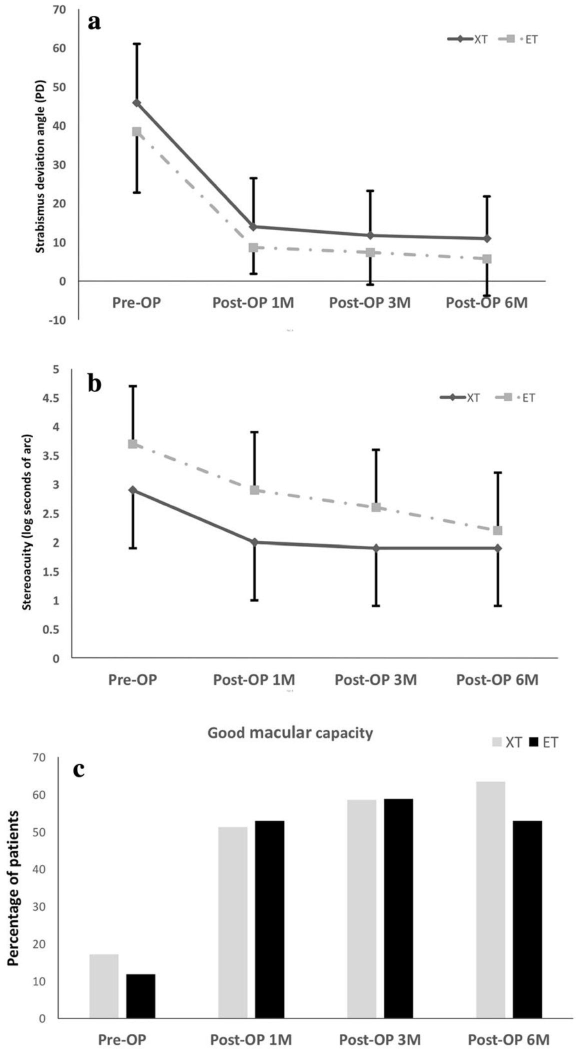

Fig. 1 **a** Change in strabismus deviation angles with time. The deviation angles were dramatically decreased at 1, 3, and 6 months postoperatively, as compared with preoperative angles ($p < 0.01$) in XT and ET groups. After surgery, the rate of improvement reached a peak at 1 month and then plateaued at 3 months. **b** Change in stereoacuity with time. As compared with preoperative status of stereopsis, the stereoacuity was significantly better from postoperative 1–6 months in XT patients ($p < 0.01$) and from postoperative 3–6 months in ET patients ($p < 0.01$). XT patients also had better postoperative stereoacuity at 6 months than 1 month ($p = 0.032$). Generally, the improvement of stereoacuity reached a peak at 1 month and persisted until 6 months after surgery. **c** The proportion of patients with good macular fusion capacity increased at 1, 3, and 6 months after surgery, as compared with before surgery. Most patients regained good macular fusion capacity at 1 month after surgery, and the proportion of patients with good macular fusion capacity did not change significantly thereafter. *OP* operation, *M* month

Factors affecting ocular alignment and sensory outcomes in XT patients

For evaluating the factors influencing the ocular alignment after strabismus surgery, patients with XT were classified as success in 20 (48.8%) and nonsuccess in 21. Preoperatively, the age of XT onset or surgery, strabismus duration, deviation angles, stereoacuity, and proportion of patients with good macular fusion capacity in success group showed no significant difference compared to the nonsuccess group. Patients had a significantly smaller deviation angles in success group than nonsuccess group from postoperative 1 ($p = 0.001$), 3, (< 0.01) to 6 months (< 0.01). There was a trend toward higher proportion of patients with final bifixation or good macular fusion capacity in success than nonsuccess group, without significance (Table 1). This result suggested that the postoperative 1-month residual smaller deviation angle (≦ 10 PD) determines the final ocular alignment, and persistent successful ocular alignment might promote partial recovery of binocular sensory functions in XT patients.

For identifying the factors affecting sensory outcome, patients with XT were classified as excellent in 16, fair in 16, and poor in 9. Preoperatively, the age of XT onset or surgery, strabismus duration, deviation angles, stereoacuity, and proportion of patients with good macular fusion capacity were not different between excellent, fair, and poor groups. In excellent group, the deviation angles showed a tendency of smaller at postoperative 1 month and decreased significantly at 6 months ($p = 0.03$), as compared with poor group. The patients in excellent group also showed significantly better stereoacuity and higher proportion of good macular fusion capacity at 1 month ($p = 0.003$ and $p = 0.023$, respectively) and 6 months after surgery ($p < 0.01$) than poor group (Table 2). These data indicated that restoration of binocular sensory functions occurred as early as postoperative 1 month and patients with excellent final binocular sensory functions seemed to have persistent better motor alignment from postoperative 1–6 months.

Factors that influence ocular alignment and sensory outcome in ET patients

In ET group, 11 patients (64.7%) were classified as successful ocular alignment. Patients in success group

Table 1 Difference between groups of successful and non-successful ocular alignments after XT or ET operation

	XT			ET		
	Success (n = 20)	Nonsuccess (n = 21)	p value	Success (n = 11)	Nonsuccess (n = 6)	p value
Sex (number of male)	7	12	0.155	7	2	0.247
Onset age (year, mean ± SD (median))	4.83 ± 4.02 (3.5)	7.41 ± 10.39 (3)	0.305	6.91 ± 6.73 (4)	2.25 ± 2.04 (1.5)	0.123
Strabismus duration (year, mean ± SD (median))	8.33 ± 6.82 (7)	11.55 ± 7.97 (10)	0.173	4 ± 5.04 (3)	16.08 ± 20.84 (5)	0.081
Age at surgery (year, mean ± SD (median))	13.15 ± 8.71 (10.5)	18.95 ± 15.45 (14)	0.149	10.91 ± 6.89 (8)	18.33 ± 22.01 (6)	0.309
Anisometropia (PD, mean ± SD)	0.70 ± 0.72	0.63 ± 1.16	0.835	0.87 ± 1.06	0.33 ± 0.43	0.514
Strabismus deviation angle (PD, mean ± SD)						
preOP	43.8 ± 14.07	47.1 ± 13.43	0.417	34.36 ± 15.12	44.17 ± 19.85	0.269
postOP_1M	7.28 ± 7.66	20.24 ± 12.98	0.001*	6.55 ± 5.15	13 ± 8.54	0.079
postOP_3M	5.45 ± 6.68	19.12 ± 11.75	< 0.01*	4.4 ± 6.55	13.2 ± 9.01	0.049*
postOP_6M	4 ± 4.55	17.55 ± 10.9	< 0.01*	2.41 ± 3.26	11.83 ± 14	0.045*
Stereoacuity (log seconds of arc, mean ± SD)						
preOP	3.09 ± 0.91	2.73 ± 0.97	0.232	3.56 ± 0.78	3.93 ± 0.18	0.277
postOP_1M	2.05 ± 0.58	2.0 ± 0.35	0.741	2.98 ± 1.04	2.92 ± 0.81	0.911
postOP_3M	1.96 ± 0.45	1.87 ± 0.28	0.460	2.18 ± 0.66	3.65 ± 0.70	0.003*
postOP_6M	1.83 ± 0.32	1.92 ± 0.34	0.390	1.95 ± 0.30	2.77 ± 0.94	0.003*
Final bifixation (%)						
postOP_6M	70	42.9	0.075	36.4	0	0.139
Good macular fusion (%)						
preOP	20	14.3	0.470	18.2	0	0.404
postOP_1M	72.2	44.4	0.088	72.7	20	0.077
postOP_3M	65	68.8	0.549	90	25	0.041*
postOP_6M	70	57.1	0.299	72.7	16.7	0.043*

PD prism diopter, *D* diopter, *SD* standard deviation, *&* tested by repeated measures of two-way ANOVA

*$p < 0.05$

had a trend of smaller postoperative deviation angles and higher proportion of patients with good macular fusion capacity than nonsuccess group at postoperative 1 month, with significance at 3 months ($p < 0.05$) and 6 months ($p < 0.05$). The stereoacuity also improved from postoperative 3 months ($p = 0.003$) to 6 months ($p = 0.003$). These data indicated residual deviation angle (≦ 10 PD) at postoperative 1 month might be a good predictor of successful final motor alignment, and persistent better ocular alignment after surgery helped forward the restoration of binocular sensory functions later in ET patients (Table 1).

For evaluating sensory outcomes, patients with ET were classified as excellent in 3, fair in 7, and poor in 7. The deviation angles and the proportion of patients with good macular fusion capacity improved significantly from postoperative 1–6-month follow-up, and there was a trend of better stereoacuity at the postoperative 3-month ($p = 0.07$) and 6-month follow-up ($p = 0.06$) in the excellent and fair groups, as compared with poor group (Table 2). This result showed that patients with excellent or fair binocular sensory outcome represented smaller deviation angles and greater portion of good macular fusion capacity, which were earlier and more dramatic than stereoacuity improvement. No preoperative factors affecting the motor and binocular sensory outcomes after surgery were identified.

Table 2 Differences between groups of good and poor sensory outcomes after XT or ET operation

	XT				ET			
	Excellent (n = 16)	Fair (n = 16)	Poor (n = 9)	p value	Excellent (n = 3)	Fair (n = 7)	Poor (n = 7)	p value
Sex (number of male)	7	7	5	0.832	2	4	3	0.755
Onset age (year, mean ± SD (median))	6.81 ± 4.45 (4.5)	5.09 ± 9.76 (2.5)	6.83 ± 9.86 (2)	0.803	6.0 ± 5.29 (4)	7.71 ± 5.29 (5)	2.5 ± 1.98 (2)	0.262
Strabismus duration (year, mean ± SD (median))	8.75 ± 4.95 (7.5)	10.16 ± 9.02 (8)	11.83 ± 8.79 (10)	0.623	7.33 ± 9.29 (3)	2.57 ± 2.15 (2)	14.36 ± 19.59 (5)	0.287
Age at surgery (year, mean ± SD (median))	15.56 ± 7.96 (17.5)	15.25 ± 15.31 (10.5)	18.67 ± 15.89 (12)	0.803	13.33 ± 8.51 (13)	10.29 ± 7.16 (8)	16.86 ± 20.44 (6)	0.705
Anisometropia (PD, mean ± SD)	0.41 ± 1.19	0.83 ± 0.67	0.92 ± 0.77	0.386	025 ± 0.35	1.24 ± 1.11	0.36 ± 0.37	0.149
Strabismus deviation angle (PD, mean ± SD)								
preOP	48.25 ± 18.07	41.94 ± 14.5	48.33 ± 10.0	0.438	28.33 ± 17.56	44 ± 22.26	35.71 ± 8.86	0.400
postOP_1M	8.78 ± 8.89	17.31 ± 13.97	18.75 ± 13.59	0.084	6 ± 5.29	4.29 ± 4.96	14.83 ± 4.75	0.006*
postOP_3M	9.8 ± 8.45	11.33 ± 13.84	16.71 ± 11.97	0.428	4.5 ± 16.26	2.57 ± 4.24	13.83 ± 5.81	0.030*
postOP_6M	8.63 ± 5.5	8.25 ± 11.79	19.83 ± 12.25	0.016*	3 ± 5.2	− 0.71 ± 6.82	13.36 ± 7.92	0.007*
Stereoacuity (log seconds of arc, mean ± SD)								
preOP	3.16 ± 1.02	2.52 ± 0.78	2.9 ± 0.97	0.159	4.00 ± 0	3.3 ± 0.9	3.93 ± 0.17	0.122
postOP_1M	1.79 ± 0.19	2.08 ± 0.36	2.46 ± 0.76	0.004*	3.2 ± 1.38	2.74 ± 0.96	3.1 ± 0.85	0.736
postOP_3M	1.78 ± 0.15	2.06 ± 0.51	1.93 ± 0.37	0.142	2 ± 0.43	2.24 ± 0.78	3.35 ± 0.91	0.070
postOP_6M	1.65 ± 0.07	1.91 ± 0.35	2.19 ± 0.31	< 0.01*	1.6 ± 0.0	2.21 ± 0.6	3.54 ± 0.54	0.064
Final bifixation (%)								
postOP_6M	100	43.8	0	< 0.01*	100	14.3	0	0.002*
Good Macular fusion (%)								
preOP	12.5	25	11.1	0.556	33.3	14.3	0	0.313
postOP_1M	81.2	50	25	0.022*	100	71.4	16.7	0.033*
postOP_3M	80	66.7	33.3	0.129	100	71.4	60	0.571
postOP_6M	100	56.2	11.1	< 0.01*	100	85.7	0	0.001*

E excellent, *F* fail, *P* poor; significance ($p < 0.05$) in paired groups shown in post hoc column

&: tested by repeated measures of two-way ANOVA

*$p < 0.05$

Difference in binocular sensory functions between successful and non-successful ocular alignment after surgery

Of all patients, those with successful ocular alignment had a higher chance to achieve excellent and fair binocular sensory outcomes (OR 5.4, $p = 0.008$) than nonsuccess cases. In ET group, patients with successful ocular alignment had significantly greater odds of excellent and fair sensory outcome, as compared with nonsuccess group (OR 22.5, $p = 0.035$ by Fisher's exact test). Patients with XT showed a trend toward excellent and fair binocular sensory outcomes when they had successful ocular alignment, without statistical significance. (OR 4.5, $p = 0.071$) (Table 3). In other words, patients diagnosed with ET might expect a better sensory outcome if successful ocular alignment is achieved, as compared with patients diagnosed with XT.

Difference between patients in XT and ET groups

There was no significant difference between XT and ET groups in sex, age of strabismus onset, duration of strabismus, age at surgery, anisometropia, preoperative and final status in deviation angles, proportion of patients with successful ocular alignment, or good macular fusion. Compared with ET patients, XT patients showed significantly better stereoacuity from pre- to postoperation ($p < 0.01$) and higher proportion of patients achieved final bifixation ($p = 0.024$), despite lower proportion with successful ocular alignment. Nevertheless, the level of stereopsis improvement was not different between XT and ET groups, as well as the proportion of patients with excellent binocular sensory function (Table 4).

Discussion

The most common strabismus types include intermittent XT, followed by constant XT and constant ET [1]. In clinical practice, surgery is often recommended for patients with poorly controlled intermittent or constant strabismus. In this study, the XT cases were about 2.4 times of ET, which might be related to natural prevalence in Asian population. The median onset age was 3 years in both ET and XT. In our patients, the duration of strabismus was approximately 3 years in ET and 8 years in XT. Therefore, most of the patients were classified as constant XT progressed from intermittent type and possibly acquired non-accommodative ET.

The success rate of ocular alignment in intermittent XT is reported as highly variable, ranging from 42 to 81% [10, 13, 14, 20–23]. Several factors are associated with residue strabismus deviation angles following surgery. Smaller preoperative deviation angles [15] and postoperative slight overcorrection are positive predictors for successful ocular alignment [18, 24]; however, anisometropia is associated with a poor outcome in XT patients [23]. Aside from ocular alignment, the restoration of binocular sensory function is a very important aspect in the determination of surgery success. Yam et al. [25] reported that 37% of patients achieved stereopsis better than 100 s of arc at a 3-year follow-up after an operation in children with intermittent XT. Buck et al. [19] showed that the median intermittent XT angle significantly decreased and that there was only marginal, not significant improvement in stereoacuity at the 6-month follow-up after surgery in children aged ≤ 12 years. The factors associated with better postoperative stereoacuity included short strabismus duration (< 5 years) and undergoing surgery at a young age (≦ 7 years old)

Table 3 Difference in sensory function between successful and non-successful motor alignment after surgery

Variable	Success	Nonsuccess	OR (95% CI)	*p* value
Excellent and fair sensory outcome				
Total	27 (64.3%)	15 (35.7%)	5.4 (1.48–19.73)	0.008*
XT	18 (56.2%)	14 (43.8%)	4.5 (0.81–25.12)	0.071
ET	9 (90%)	1(10%)	22.5 (1.61–314.56)	0.035*

XT exotropia, *ET* esotropia

*$p < 0.05$

Table 4 Difference in pre- and postoperative variables between patients of XT and ET

	XT (n = 41)	ET (n = 17)	p value
Sex (number of males)	19	9	0.650
Onset age (year, mean ± SD (median))	6.15 ± 7.96 (3)	5.27 ± 5.91 (3)	0.680
Strabismus duration (year, mean ± SD (median))	9.98 ± 7.52 (8)	8.27 ± 13.68 (3)	0.540
Age at surgery (year, mean ± SD (median))	16.12 ± 12.81 (12)	13.53 ± 13.92 (7)	0.500
Anisometropia (PD, mean ± SD)	0.67 ± 0.94	0.75 ± 0.90	0.770
Preoperative deviation (PD, mean ± SD)	45.80 ± 15.20	37.82 ± 17.00	0.080
Final successful alignment (%)	48.8	64.7	0.268
Preoperative stereoacuity (log seconds of arc, mean ± SD)	2.85 ± 0.95	3.69 ± 0.65	0.002*
Final stereoacuity (log seconds of arc, mean ± SD)	1.87 ± 0.33	2.24 ± 0.60	0.004*
Final bifixation (%)	56.1	23.5	0.024*
Stereopsis improvement (%)	70.7	70.6	0.991
Preoperative good macular fusion (%)	17.1	11.8	0.611
Final good macular fusion (%)	63.4	52.9	0.458
Sensory function_excellent (%)	39	17.6	0.192

SD standard deviation, *PD* prism diopter

*$p < 0.05$

[26], fine to moderate (40–250 s of arc) preoperative stereoacuity, preoperative macular fusion, or postsurgical orthotropia [7]. The success rate of ocular alignment in our patients with XT was 49, and 56.1% patients achieved bifixation. Patients who achieve smaller deviation angles (≦ 10 PD) at postoperative 1 month may expect to have successful final ocular alignment. Similarly, the stereoacuity and macular fusion capacity at 1 month after surgery determined the final binocular sensory functions, when the residue deviation angles were smaller in excellent than poor groups. There was a trend of positive correlation between success ocular alignment and excellent binocular sensory functions. However, no preoperative factors including strabismus duration (< 5 vs. ≧ 5 years) and age at surgery (≦ 7 vs. > 7 years old) were predictors of the final outcome (Table suppl. 1). As compared with previous studies, we observed a lower rate of successful ocular alignment but higher rate of bifixation. This could be explained by the larger preoperative deviation angles in most patients enrolled in our study, though their onset age of strabismus was later than the critical period of sensory development and thus, binocular sensory functions would be restored on achieving better ocular alignment after surgery. This presumption also considers that only postoperative, and not preoperative, factors influenced the surgical outcomes in XT patients.

In patients with acquired non-accommodative ET, previous study reported 66% success rate of ocular alignment (≦ 10 PD of orthophoria) [27]. Chan et al. [28] also reported that in ET cases with successful ocular alignment, 82.3% patients had macular fusion. Between 6.3 and 14.7% of patients had postoperative bifixation [28, 29], which was correlated with a later age at onset (> 4 years) or diagnosis and smaller preoperative deviation angle [29]. In our study, the success rate of ocular alignment was 65 and 23.5% of ET patients who achieved bifixation at 6 months after surgery. Seventy-three percent of ET patients had good macular fusion capacity when motor alignment was successful. Patients who achieved smaller postoperative deviation angles (≦ 10 PD) at postoperative 1 month may expect to have successful ocular alignment and excellent binocular sensory functions including better stereoacuity and good macular fusion. However, none of the preoperative factors including age of onset or diagnosis (≦ 4 vs. > 4 years) were predictors of the final outcomes (Table suppl. 1).

The difference of surgical outcomes between XT and ET has rarely been reported. In our study, we found the pre- and postoperative stereoacuity was significantly better and the proportion of patients achieving bifixation was higher in XT than ET, despite relatively shorter duration of strabismus in ET. However, in the final success rate of ocular alignment, the proportion of patients with final good macular fusion capacity and the level of stereoacuity improvement did not differ. Nevertheless, stronger relationship between excellent/fair sensory outcomes and successful ocular alignment was shown in ET patients. This result indicated that while the prognosis was similar in ocular alignment and binocular sensory functions after surgery in both major types of strabismus, patients might develop constant ET earlier than XT. This would result in a greater effect on stereoacuity; hence, surgery should be recommended earlier in ET patients for restoration of binocular sensory functions.

The limitations of our study include the analysis of the motor and sensory functions in only near-distance targets, the use of the Titmus stereotest to examine stereoacuity, a small sample size, a short follow-up time, and possible recall bias of strabismus history. In our clinical experience, patients with strabismus, especially children, pay more attention to the near target than distant. Therefore, the collected data from near targets would be more convincing than far distance targets. To avoid overestimation of stereoacuity from image clues in the Titmus stereotest, we graded stereoacuity as bifixation, gross, and nil to evaluate the improvement of stereopsis. Studies have shown that the residue deviation angle increases with time [18]. Recurrent postoperative exodrift is an important phenomenon that occurs at 1–6 weeks after surgery. The postoperative follow-up interval and the first follow-up time after surgery for strabismus patients varied among previous studies, with total follow-up time from 6 months to 3 years, 3 months first follow-up time after operation, and follow-up interval from 2 to 6 months [30–33]. Some studies showed that shorter interval of follow-up at postoperative 1 week and 1 month may increase success rate of motor alignment in early achievement of successful alignment. However, the postoperative angle change is variable and unstable during the early months after surgery [32]. In our study, we set the first follow-up at 1-month, because postoperative instability was high within 1 month. In addition, significant improvement in motor and binocular sensory function was noted at 1 month after operation. Therefore, we speculated that postoperative 1-month motor alignment and binocular sensory functions might be the reliable and optimal index for prognosis.

Recurrence was most commonly seen during the first 6 months after surgery in intermittent exotropia [34]. In our study, the rate of improvement in all motor and sensory functions was rapidly elevated at 1 month, then slowed down, and reached plateau at 3 and 6 months after surgery. The difference between success and nonsuccess in ocular alignment, excellent and poor sensory function could be discriminated before 6 months. The duration of follow-up of 6 months was likely adequate to determine the factors affecting surgical outcomes.

In conclusion, patients with poor controlled strabismus, either with XT or ET, achieved improvement in ocular alignment and binocular sensory functions, as early as 1 month following surgery. The postoperative 1-month deviation angle < 10 PD seemed to be a factor for favorable ocular alignment, and persistent better ocular alignment promoted the restoration of binocular sensory functions. Compared with XT patients, ET patients could recover more binocular sensory functions if postoperative successful ocular alignment is achieved, although stereoacuity was more depressed preoperatively and improved later during follow-up after surgery. Therefore, strabismus surgery should be recommended earlier in ET patients; in addition, it is important to maintain postoperative residue deviation angle < 10 PD in all strabismus patients for better binocular sensory outcomes.

Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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