

Predictive factors of stereopsis outcomes following strabismus surgery

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Ther Adv Ophthalmol

2021, Vol. 13: 1–8

DOI: 10.1177/
25158414211003001

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Abstract

Purpose: To determine the predictive factors of post-operative stereopsis in patients with strabismus.

Method: In this retrospective study, records of patients who received surgical treatment for strabismus were reviewed. All types of strabismus were included. Pre- and post-treatment stereoacuity were measured using the Titmus Stereo Fly test, and predictive factors of stereopsis were evaluated.

Results: A total of 194 patients (132 females and 62 males) with a mean age of 14.8 ± 8.4 years were included. There was a statistically significant improvement in stereopsis following surgery (p value < 0.001). Patients with a higher amount of deviation at baseline had poorer stereopsis on the final examination (p value < 0.001). Stereopsis improvement was more prominent in the pure horizontal strabismus group, compared to combined horizontal and vertical deviations. Baseline and the final stereopsis were higher in the “exotropia” group as compared to the “esotropia” group (p value = 0.003 and 0.0155, respectively); however, the within group change of stereopsis was not significantly different between these two groups (p value = 0.144). Post surgical residual deviation was associated with a poorer stereopsis (p value = 0.002, $r = 0.251$). A longer duration of strabismus before surgery was associated with poorer final stereopsis levels (p value = 0.026). The presence of amblyopia before surgery was associated with poorer stereopsis on last examination (p value < 0.001 for both correlations).

Conclusion: Based on the result of this study, final stereopsis after strabismus surgery could be affected by the type, duration, and the amount of deviation before surgery, amblyopia, and post operative ocular deviation.

Keywords: predictive factors, stereopsis, strabismus, treatment

Received: 28 January 2021; revised manuscript accepted: 23 February 2021.

Introduction

Normal binocular vision with high-level stereopsis is necessary for skilled performance.¹ Improvement of the stereoacuity is associated with a better long-term quality of life.² Therefore, the restoration of stereopsis in patients who have lost their binocular vision is extremely valuable. Considering the high incidence of binocular dysfunction in patients with strabismus,³ it is important to determine the effect of surgical and nonsurgical management of strabismus on the stereopsis outcomes.

In acquired strabismus, it is believed that the treatment of the double vision may recover the

patient’s earlier capacity of stereopsis.⁴ Moreover, in children with congenital strabismus, appropriate intervention within the first few years of life may improve the binocular function. Recently, it is suggested that stereopsis can improve even in adults with long-standing childhood strabismus.⁵

Post-operative alignment,⁶ duration of misalignment prior to treatment,⁷ presence of amblyopia,⁸ type of deviation, and amount of deviation before treatment,⁶ are reported to influence the binocular outcomes of strabismus surgery. However, the conditions under which higher levels of stereoacuity can be acquired remains to be a topic for investigation.

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In this retrospective study, we evaluated the effect of surgical ocular realignment on the improvement of stereopsis in patients with different types of strabismus, and in addition, we determined the prognostic factors of the better sensory outcome.

Method

Patient selection

We identified patients who underwent strabismus surgery between 2014 and 2019. All procedures were performed by a single fellowship-trained surgeon. Exclusion criteria were age younger than 7 years old at final visit, deep amblyopia (best corrected visual acuity (BCVA) less than 20/200), incomplete follow-up examinations, or developmental and neurologic abnormality. We collected the data including age, gender, current BCVA, the age at the time of surgery, type of the strabismus, amount of the deviation before treatment, duration of the strabismus, and pre-treatment stereopsis. Finally, stereopsis on 1 year and last follow-up visits were recorded. The main variables of the study included the type of the strabismus, amount of the ocular deviation, age of treatment, final ocular alignment, and amblyopia.

Measurement of stereopsis

Pre- and post-operative stereopsis testings were performed by a single ophthalmologist using the Titmus Stereo Fly test. The results of the stereopsis measurement were categorized as null (stereopsis worse than 3000s of arc), poor stereopsis (3000–800s of arc), moderate stereopsis (800–100s of arc), and fine stereopsis (better than 100s of arc). All pre- and post-operative measurements of ocular deviation (using the simultaneous prism and cover or modified Krimsky test), and strabismus surgeries were performed by a single strabismus surgeon. The successful alignment was defined as orthotropia or horizontal heterotropia of 10PD or less and vertical deviation of 5PD or less at distance and near.

Statistical analysis

To present the data, we used mean, standard deviation, median and range, frequency, and percent. To assess the improvement within the groups, we used the Wilcoxon Singed Rank test. To evaluate the difference between the groups, we used the Mann–Whitney and Kruskal–Wallis

tests. Also, whenever needed, we used generalized estimating equations (GEEs) to consider the possible correlation of the results in the eyes. Correlation of variables was assessed by the Spearman correlation coefficient and the Partial correlation coefficient (whenever adjustment for two eyes from one patient is needed). In the last step, to consider the baseline status of stereopsis in comparison to the groups, we used ordinal logistic regression. All statistical analyses performed by SPSS (IBM Corp, Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.). A p value of less than 0.05 was considered statistically significant.

Results

A total of 194 patients (132 females and 62 males) were included. The mean age of patients was 14.8 ± 8.4 years. The baseline stereopsis is summarized in Table 1.

There was a statistically significant improvement of stereopsis following strabismus surgery at 1 year and final follow-up visit (p value < 0.001). The rate of fine stereopsis increased from 10.5% at preoperative visit to 24.2% at final visit. Also, the rate of null stereopsis decreased from 50.5% at pre-treatment evaluations to 36.8% at final visit. In addition, there was no significant relationship between the final stereopsis and the patients' age and gender (p value = 0.431 and 0.462, respectively).

Patients with horizontal deviation enjoyed a significant improvement of stereopsis after surgery (p value < 0.001 for both esotropia and exotropia groups). Both baseline and final stereopsis was significantly higher in the “exotropia” group as compared to the “esotropia” group (p value = 0.003 and 0.015 for baseline and final stereopsis, respectively). However, postoperative changes of stereopsis were not significantly different between two groups (p value = 0.144; Table 2). In patients with esotropia secondary to sixth cranial nerve palsy, and in patients with intermittent exotropia, the improvement of stereopsis following surgery were not statistically significant (p value = 0.31 and 0.067, respectively).

Stereopsis did change significantly after surgery in patients with concomitant vertical deviation (Table 3). However, stereopsis improvement was

more in the pure horizontal strabismus group, compared to combined horizontal and vertical deviations. Among these patients, those with concomitant inferior oblique overaction (IOOA), dissociated vertical deviation (DVD), and superior oblique palsy (SOP), experienced a significant improvement of stereopsis following surgery (p value = 0.001, 0.005, and 0.007, respectively).

Regarding the relationship between the stereopsis and the outcome of strabismus surgery, we observed that worse baseline stereopsis was not associated with a higher final residual deviation. However, post-surgical residual deviation was associated with a poorer stereopsis (p value = 0.002, $r=0.251$; Table 4).

Patients with higher amount of deviation at baseline and longer duration of strabismus before surgery had worse stereopsis on final examination (p value < 0.001 and 0.026, $r=0.223$ and 0.14, respectively; Table 5).

Anisometropia at baseline was correlated with poor stereopsis outcomes. Similarly, the presence of amblyopia before surgery was associated with poorer stereopsis on last examination (p value < 0.001 for both correlations; Table 6).

Discussion

In this study, we evaluated postoperative stereopsis in 194 patients with different types of strabismus. In line with previous studies, we found that strabismus surgery significantly improved the stereopsis. A long period of preoperative ocular misalignment, baseline amblyopia, and a larger preoperative deviation were associated with poorer stereopsis. Although the baseline stereopsis was significantly higher in exotropia group, compared to esotropic patients, strabismus surgery in both esotropia and exotropia groups was associated with a significant improvement of stereopsis. In patients with horizontal strabismus, the coexistence of vertical deviation had a negative effect on the final stereopsis. Following surgery, the improvement of stereopsis in infantile and accommodative esotropic patients was significant, while for sixth nerve palsy patients, stereopsis improvement was not statistically significant. Similarly, in patients with intermittent esotropia, the change of stereopsis was not statistically significant. It may be explained by the fact that intermittent exotropic patients had a bet-

Table 1. Baseline characteristics of study patients.

Parameter	Value
Age at the time of surgery (n (%))	
<5 years	28 (14.4%)
5–10 years	98 (50.5%)
11–15 years	18 (9.2%)
16–20 years	10 (5.1%)
21–25 years	6 (3%)
26–30 years	4 (2%)
31–35 years	5 (2.5%)
36–40 years	15 (7.7%)
41–45 years	7 (3.6%)
46–50 years	3 (1.5%)
Sex (n (%))	
Female	132 (69.7%)
Male	62 (30.3%)
Baseline stereopsis (>4 years old) (n (%))	
Fine	20 (10.5%)
Moderate	42 (22.1%)
Poor	32 (16.8%)
Null	96 (50.5%)
Type of deviation (n (%))	
ET	92 (45%)
XT	96 (47%)
Vertical	51 (25%)
Average follow-up period until final visit (month, mean \pm SD)	39 \pm 4.21
ET, esotropia; SD, standard deviation; XT, exotropia.	

ter baseline stereopsis, compared to constant exotropic cases and esotropic patients.

As a vital feature of normal visual function, stereopsis is a form of depth perception driving from binocular vision that attains its adult level between 7 to 9 years old.⁹ Disruption of normal binocular fusion (e.g., due to strabismus) may have an impact

Table 2. Improvement of stereopsis in main horizontal groups of strabismus without concomitant vertical deviation.

Horizontal deviation	Deviation subtype	Pre-treatment				Last visit				p value
		Fine (n)	Moderate (n)	Poor (n)	Null (n)	Fine (n)	Moderate (n)	Poor (n)	Null (n)	
ET	Infantile	0	3	4	44	3	22	1	25	<0.001
	Accommodative	1	3	2	10	3	10	1	2	<0.001
	Sixth nerve palsy	1	5	0	0	6	0	0	0	0.31
	Total	2	11	6	54	12	32	2	27	<0.001
XT	Intermittent	10	15	4	12	20	12	0	5	0.067
	Constant	3	7	7	14	11	10	2	12	<0.001
	Total	13	22	11	26	31	22	2	17	<0.001
p value		0.003				0.015				

ET, esotropia; XT, exotropia.

Table 3. Improvement of stereopsis in main horizontal groups of strabismus with concomitant vertical deviation.

Horizontal deviation	Concomitant vertical deviation	Pre-treatment				Last visit				p value
		Fine (n)	Moderate (n)	Poor (n)	Null (n)	Fine (n)	Moderate (n)	Poor (n)	Null (n)	
ET or XT	I00A	0	1	3	10	1	3	1	8	0.001
	SOP	0	1	3	11	1	3	4	7	0.007
	DVD	1	2	1	2	2	3	0	1	0.005
	Duane syndrome	1	2	1	1	1	3	1	0	0.06
	Brown syndrome	1	1	0	1	1	2	0	0	0.08
	Total	3	7	8	25	6	14	6	16	<0.001

DVD, dissociated vertical deviation; ET, esotropia; I00A, inferior oblique overaction; SOP, superior oblique palsy; XT, exotropia.

on the fine visual motor actions, stereopsis, and spatial resolution.¹⁰

Strabismus in the first few years of life inhibits the development of binocular sensory neurons in the brain.¹¹ The long duration of plasticity in maturation of stereopsis (until the end of the first decade of life) expose binocular vision to disruption until higher ages, for example, by the onset of accommodative esotropia in toddlerhood.¹² Moreover, it has been postulated that strabismus may damage stereoacuity even in visually mature patients.¹³ Conversely, the window for recovery of stereopsis seems to remain open for longer period as there are reports of strabismus patients achieving stereopsis as adults, many years after the onset of ocular deviation.¹⁴

It was first believed that a congenital defect of fusion prevents development of binocularity in congenital strabismus.¹⁵ Later, it had been shown that treatment of ocular misalignment in childhood, may provide the opportunity to develop binocularity.¹⁶⁻²⁰ Not only for patients treated in childhood, some studies revealed that even with large angle and long standing heterotropia, good binocularity and stereopsis may be achieved. In a retrospective study, Scott and colleagues²¹ found that almost one-third of patients treated after binocular maturity had some sensory fusion and stereopsis postoperatively. Similarly, Gill and Drummond²² confirmed postoperative improvement of stereopsis in visually mature patients. These findings were

Table 4. The relationship between residual deviation and stereopsis after treatment.

Visit	Stereopsis category	Final residual deviation	
		Mean \pm SD	Median (range)
Before surgery	Fine	6.58 \pm 2.35	6 (3–10)
	Moderate	8.47 \pm 3.31	8 (0–15)
	Poor	7.71 \pm 3.8	7 (2–20)
	Null	8.59 \pm 4.78	7 (3–30)
r		0.019	
p value		0.821	
Final visit	Fine	6.76 \pm 2.41	7 (3–12)
	Moderate	7.98 \pm 4.4	7 (0–30)
	Poor	7.5 \pm 3.44	6 (5–16)
	Null	9.93 \pm 5.42	9 (4–30)
r		0.251	
p value		0.002	
SD, standard deviation. (r: Spearman correlation).			

Table 5. The relationship between final stereopsis and the amount and duration of initial deviation.

	Stereopsis	Baseline deviation (PD, median (range))	Baseline deviation more than 30 PD (n (%))	Duration of misalignment before surgery (month, mean \pm SD)
Final visit	Fine	25 (6–47)	10 (5.1)	92 \pm 87
	Moderate	30 (0–65)	19 (9.7)	97 \pm 107
	Poor	27 (0–60)	29 (14.9)	108 \pm 95
	Null	35 (0–85)	37 (19)	125 \pm 111
r		0.223		0.14
p value		< 0.001	0.023	0.026
SD, standard deviation. (r: Spearman correlation)				

replicated in other studies.^{2,4,6,23} A recent study showed that strabismus surgery in adults can increase the quality of life by improving stereoacuity.²⁴ The results of our study confirm the findings of previous studies in which postoperative orthotropia is associated with better stereopsis outcomes.

Early surgical intervention is shown to improve the stereopsis in patient with acquired esotropia⁷ and exotropia.²⁵ Kassem and Elhilali⁷ reported that almost 80% of patients who had a misalignment of 4 years' duration or less achieved postoperative fusion compared to only 24% of patients who had a misalignment of longer than 4 years'

Table 6. The relationship between baseline anisometropia and amblyopia, and final stereopsis.

Stereopsis level at final visit	Baseline Anisometropia		Baseline amblyopia	
	Yes	No	Yes	No
Fine	3 (11.1%)	58 (25.0%)	14 (13.2%)	50 (32.6%)
Moderate	4 (14.8%)	88 (38.0%)	34 (32.1%)	60 (39.2%)
Poor	2 (7.4%)	18(7.8%)	7 (6.6%)	17 (11.1%)
Null	18 (66.7%)	68 (29.3%)	51 (48.1%)	26 (17.0%)
<i>R</i>	0.222		0.317	
<i>p</i> value	<0.001		<0.001	

duration. Abroms and colleagues²⁵ reported that patients with intermittent or constant exotropia may achieve superior sensory outcome when they are treated before 5 years of strabismus duration. In accordance with these findings, we observed that those with longer period of ocular misalignment before surgery had lower levels of postoperative stereopsis. However, it is possible to achieve good postoperative stereopsis outcomes even in the chronic misalignment.⁶ Lal and Holmes²⁶ found that ocular misalignment for up to 4 years may not affect the development of postoperative stereoacuity in acquired strabismus in adulthood. Furthermore, it has been reported that adults with horizontal strabismus for more than 10 years achieved a good stereopsis after surgical correction.^{6,27}

We found that pre-operative amblyopia was associated with poor post-operative stereopsis outcomes. It is believed that impaired stereopsis is the most common deficit associated with amblyopia.²⁸ Also, it has been postulated that stereopsis is more impacted in strabismic than in anisometropic amblyopia, and the response of strabismic amblyopia to common amblyopia treatment protocols is poorer, compared to other types of amblyopia.²⁹ Stewart and colleagues⁸ showed that stereoacuity could be improved with treatment of amblyopia; however, poor visual acuity of amblyopic eye was associated with a poor final stereopsis. Similarly, Wallace and colleagues³⁰ reported that subnormal stereoacuity persisted after a course of amblyopia treatment, even when their visual acuity and binocular function effectively resolved. Poor final stereopsis of our amblyopic patients may be justified by either the destructive effect of amblyopia on potential final stereoacuity, or by the fact that individuals

with strabismic amblyopia have a low probability of improvement with single surgical intervention and monocular trainings, since they may have required more direct stereo training to achieve better stereopsis.²⁹

In our study, earlier manifestation of ocular misalignment was related to poorer post-operative outcomes. The period of maturation of stereopsis is considered to be the first decade of life, and any defect in binocularity in this critical period could damage the process of stereopsis maturation. Our observation revealed that those with higher amount of deviation at baseline had poorer stereopsis at final visit. This result is in contrast with two previously published studies, where the amount of pre-treatment deviation did not affect the final stereopsis.⁶ We believe that higher amount of ocular deviation is associated with an immature stereopsis, which is not completely reversible by the treatment. We found that stereopsis improved in both pure horizontal and combined horizontal vertical deviations. However, pure horizontal strabismus patients had a significantly better final stereopsis. In intragroup analysis, patients with exotropic strabismus had a higher level of baseline and final stereopsis; however, the amount of changes in stereopsis was comparable between eso and exodeviation. Also, we showed that lower amount of residual ocular misalignment correlates with a better stereopsis. Other studies have yielded the same conclusion as ours that post surgical orthotropia yields better stereopsis, compared to larger degree of residual deviation.^{6,31}

Limitations of this study are inherent to its retrospective nature. Measurement of stereopsis with the Titmus stereo test is another limitation of our

study since the test result can be affected by some monocular clues.³² In summary, we found that the longer duration of ocular misalignment before surgery, combined horizontal vertical strabismus, larger amount of deviation, amblyopia, and residual strabismus are associated with poorer post-operative stereopsis outcomes.

Author Contributions

M.E. and S.E. designed the study and prepared the proposal; S.B. gathered the data; A.A. and T.S. analyzed the data; and A.A. and H.E. prepared the manuscript.

Conflict of interest statement

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethics statement

The ethics committee of Shahid Beheshti University of Medical sciences and ethical board of Imam Hossein hospital, Tehran, approved this study in May, 2018. According to the ethics committee, the need for an informed consent and ethical code was waived for this retrospective case series. Our research adhered to the tenets of the Declaration of Helsinki.

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Data availability statement

The data sets during and/or analyzed during this study are available from the corresponding author on reasonable request.

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