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Original Article

Progression of Stereopsis Recovery in Strabismic Patients: A One-Month and Three-Month Post-Surgery Evaluation

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ABSTRACT

Background: Strabismus, a misalignment of the eyes, disrupts binocular vision and stereopsis, impairing depth perception and functional visual tasks. Surgical correction aims to restore ocular alignment and may improve stereoacuity, yet the early postoperative trajectory of stereopsis recovery remains incompletely defined. Objective: To evaluate the progression of stereopsis recovery and associated changes in visual acuity and ocular alignment at one- and three-months following strabismus surgery. Methods: In this prospective longitudinal observational study, 34 patients aged 8–22 years with esotropia, exotropia, hypertropia, or hypotropia underwent standardized strabismus surgery at a tertiary eye care centre. Preoperative and postoperative assessments at one and three months included best-corrected visual acuity (Snellen chart), ocular deviation (prism cover tests), and stereoacuity (Titmus fly test, arc seconds). Friedman tests with Bonferroni-corrected post-hoc analyses determined statistical significance (p<0.05). Results: By three months, 6/6 visual acuity improved from 14.7% to 38.2% in right eyes and from 20.6% to 38.2% in left eyes (p<0.001). Mean ocular deviation decreased significantly from 30 PD in 82.4% of patients preoperatively to 0 PD in 41.2% at three months (p<0.001). Stereoacuity improved from 1861.76±1235.83 to 770.88±1084.76 arc seconds (p<0.001), with aligned patients demonstrating the greatest gains. Conclusion: Strabismus surgery yields substantial improvements in alignment, visual acuity, and stereoacuity within three months, with optimal outcomes observed in patients achieving complete alignment.
Keywords: Strabismus, stereopsis, stereoacuity, ocular alignment, exotropia, esotropia, strabismus surgery.

INTRODUCTION

Strabismus, a misalignment of the eyes where one eye deviates inwards, outwards, upwards, or downwards, remains a significant ophthalmic concern across all age groups but most commonly affects children (1). Its global prevalence ranges from approximately 2% to 3%, with variation based on ethnicity and geographical region, underscoring its public health relevance (2). Several etiological factors contribute to the development of strabismus, including refractive errors, abnormalities in binocular fusion, neuromuscular dysfunction of the extraocular muscles, low birth weight, prematurity, maternal smoking during pregnancy, family history, and systemic conditions such as Down syndrome and cerebral palsy (3,4). Strabismus can be broadly categorized based on the direction of deviation: esotropia (inward turning), exotropia (outward turning), hypertropia (upward turning), and hypotropia (downward turning), with esotropia generally reported as the most common form in pediatric populations globally, although certain studies indicate variable predominance based on specific regional or racial factors (5,6).

The primary functional deficit arising from strabismus is impaired binocular vision, most notably a reduction or loss of stereopsis—the brain's ability to merge two slightly disparate retinal images into a unified, three-dimensional percept essential for depth perception (14). Stereopsis plays a fundamental role in daily activities that require spatial judgment and fine motor coordination, including reaching, grasping, and tasks necessitating hand-eye coordination such as threading a needle or operating machinery (18). Early onset strabismus, if left untreated, may result in permanent deficits in stereopsis, while later-onset or acquired forms can induce symptomatic diplopia and visual discomfort (10,17). Timely intervention—particularly surgical alignment—has been shown to restore not only ocular alignment but also has the potential to reestablish varying degrees of binocular visual function, depending on patient age, chronicity, and the absence of complicating factors like amblyopia or neurological comorbidities (7,11,12). Standardized measures such as the Titmus fly test, TNO, and Frisby test provide objective quantification of stereoacuity, and advances in assessment methodology continue to refine our understanding of functional recovery post-intervention (15).

Despite established clinical guidelines recommending surgical correction for persistent or functionally significant strabismus, the literature demonstrates variability in the extent and timeline of postoperative recovery of stereopsis, particularly within the crucial early months following surgery. Previous studies highlight that while ocular alignment can be anatomically corrected, the restoration of stereoacuity is influenced by multiple variables, including age at intervention, type and duration of deviation, preoperative sensory status, and the precision of postoperative alignment (17,19,21). For example, Eshaghi et al. identified preoperative factors such as the presence of amblyopia and larger baseline deviations as limiting to stereopsis recovery, suggesting that careful patient selection and early intervention may optimize outcomes (17). Similarly, other reports underscore that even delayed surgical realignment can yield meaningful improvements in stereopsis, particularly in young patients and those with exotropic deviations (19). However, the critical period and dynamics of stereopsis recovery—especially during the first three months post-surgery—remain incompletely defined, with few studies providing prospective, serial quantitative assessments within this window.

Given these gaps, the present study aims to prospectively evaluate the progression of stereopsis recovery in patients with strabismus undergoing corrective surgery, with assessments at one month and three months postoperatively. By employing standardized measurement tools and rigorous statistical analysis, this study seeks to clarify the trajectory of binocular function restoration, address the short-term impact of surgical intervention on stereoacuity, and provide evidence to guide clinical decision-making regarding postoperative expectations. The central research question guiding this investigation is: To what extent does stereopsis recover in strabismic patients within one and three months following surgical realignment, and what clinical and demographic factors are associated with early recovery of binocular function

MATERIAL AND METHODS

This investigation was designed as a prospective longitudinal observational study aimed at assessing the short-term progression of stereopsis recovery in patients undergoing corrective surgery for strabismus. The design was selected to enable repeated measures on the same individuals over a defined postoperative period, thereby allowing for within-subject comparisons and minimizing inter-individual variability. The study was conducted at Sajjad Eye Care, Burewala, over a four-month period from March 2025 to June 2025, with postoperative follow-up assessments performed at one month and three months after surgery. The clinical setting was chosen for its specialized ophthalmic surgical services and consistent patient population, ensuring standardized preoperative and postoperative evaluation conditions. Participants were eligible for inclusion if they were between the ages of 5 and 30 years, had a best-corrected visual acuity (BCVA) of at least 6/12 in both eyes, and were diagnosed with strabismus in the form of esotropia, exotropia, hypertropia, or hypotropia warranting surgical correction. Exclusion criteria included a history of amblyopia, previous ocular surgery, or neurological disorders that could affect ocular motility or binocular function, in order to control for confounding sensory deficits. Eligible participants were identified from surgical waiting lists and outpatient clinics using purposive sampling to ensure adequate representation of different strabismus subtypes. Each patient and/or their guardian received a detailed explanation of the study objectives, procedures, and potential risks, following which written informed consent was obtained prior to enrollment, in accordance with ethical guidelines.

Data collection followed a standardized protocol to ensure reproducibility. Preoperative assessment included measurement of visual acuity using a Snellen chart, determination of ocular alignment through the cover-uncover test and alternate prism cover test (quantified in prism diopters), and evaluation of stereopsis using the Titmus fly test, which measures stereoacuity in arc seconds. The same examiner, blinded to previous measurements, conducted all postoperative assessments at both one and three months to minimize measurement bias. All surgical interventions followed uniform clinical protocols appropriate to the type of deviation, with the surgical technique and muscle selection determined by preoperative measurements and surgeon judgment. The primary outcome variable was stereoacuity, with secondary outcomes including visual acuity and angle of deviation. Stereoacuity improvement was operationally defined as a reduction in arc second threshold values, indicating finer depth discrimination. To reduce potential sources of bias, strict inclusion/exclusion criteria were applied, measurement tools were calibrated before each use, and all assessments were conducted under consistent environmental conditions. The sample size of 34 patients was determined using G*Power software, based on an expected moderate effect size, a significance level of 0.05, and a power of 0.80 for repeated-measures analysis, allowing detection of clinically meaningful differences over time. Missing data were minimized through reminder calls for follow-up visits; when present, incomplete data points were excluded from the relevant time-point analysis without imputation, given the small proportion of missingness and its random occurrence.

Statistical analysis was conducted using SPSS version 26 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for demographic and baseline clinical characteristics. The Friedman test for related samples was used to assess changes in continuous outcomes (stereoacuity, visual acuity, prism diopters) across the three time points, as this non-parametric method accounts for non-normal data distributions and repeated measures. Post-hoc pairwise comparisons with Bonferroni correction were planned to identify specific time-point differences where overall significance was observed. Categorical variables were analyzed using the McNemar or Cochran's Q test, as appropriate. A two-tailed p-value of less than 0.05 was considered statistically significant. Subgroup analyses were pre-specified to compare recovery patterns between different types of strabismus. Ethical approval for this study was obtained from the Institutional Review Board of Superior University Lahore (Ref: IRB/FAHS/REHAB/02/25/MS/RS-3682), and all procedures adhered to the tenets of the Declaration of Helsinki (22). Data integrity was safeguarded through double data entry verification, regular cross-checks between paper forms and electronic databases, and secure storage of identifiable information on password-protected systems. The methodology was designed to be fully reproducible by any researcher following the same inclusion criteria, measurement tools, surgical protocols, and statistical approach.

RESULTS

The results of this prospective observational study reveal consistent, statistically robust improvements across all measured domains of visual function and ocular alignment following strabismus surgery. The study population consisted of 34 patients, with a mean age of 16.24 years (SD 4.00; 95% CI, 15.03–17.45), including 32.4% males and 67.6% females. The distribution of strabismus types at baseline comprised 26.5% esotropia, 32.4% exotropia, 20.6% hypertropia, and 20.6% hypotropia. Regarding visual acuity, there was a clear and statistically significant postoperative improvement in both eyes. Preoperatively, only 14.7% of right eyes and 20.6% of left eyes achieved

6/6 best-corrected visual acuity. By three months post-surgery, these proportions increased to 38.2% in both eyes. Conversely, the proportion of patients with 6/12 visual acuity in the right eye dropped from 58.8% preoperatively to 20.6% at three months, and similarly in the left eye from 50.0% to 20.6%. These differences were highly significant (Friedman test, $p < 0.001$ for both eyes), with Cohen's W effect sizes of 0.60 and 0.57 for right and left eyes, respectively, reflecting large clinical effects.

Table 1. Demographic and Baseline Clinical Characteristics of Study Participants (n = 34)

Variable	Value	95% CI
Age, mean ± SD (years)	16.24 ± 4.00	15.03 – 17.45
Age range (years)	8 – 22	–
Sex, n (%)		
Male	11 (32.4%)	17.2 – 50.6%
Female	23 (67.6%)	49.4 – 82.8%
Strabismus type, n (%)		
Esotropia	9 (26.5%)	13.2 – 44.6%
Exotropia	11 (32.4%)	17.2 – 50.6%
Hypertropia	7 (20.6%)	8.7 – 37.9%
Hypotropia	7 (20.6%)	8.7 – 37.9%

Table 2. Comparison of Visual Acuity (VA) Outcomes in Right and Left Eyes Pre- and Postoperatively

VA Category	OD (Right Eye)	Months		OS (Left Eye)	Months		p-value (OD)	p-value (OS)
	Pre-op n (%)	1st n (%)	3rd n (%)	Pre-op n (%)	1st n (%)	3rd n (%)		
6/6	5 (14.7)	2 (5.9)	13 (38.2)	7 (20.6)	3 (8.8)	13 (38.2)	<0.001	<0.001
6/9	9 (26.5)	9 (26.5)	14 (41.2)	10 (29.4)	11 (32.4)	14 (41.2)		
6/12	20 (58.8)	18 (52.9)	7 (20.6)	17 (50.0)	15 (44.1)	7 (20.6)		
6/18	0 (0.0)	3 (8.8)	0 (0.0)	0 (0.0)	4 (11.8)	0 (0.0)		
6/24	0 (0.0)	2 (5.9)	0 (0.0)	0 (0.0)	1 (2.9)	0 (0.0)		
Effect size (Cohen's W)							0.60 (large)	0.57 (large)

Interpretation: Significant improvement in best-corrected visual acuity for both eyes was observed postoperatively (Friedman test, $p < 0.001$). Cohen's W effect size indicates a large clinical effect.

Table 3. Angle of Deviation (Prism Diopters, PD) Over Time

Deviation (PD)	Pre-op n (%)	1-Month n (%)	3-Month n (%)	p-value	95% CI for Mean Change	Effect Size (Kendall's W)
15	6 (17.6)	15 (44.1)	10 (29.4)			
30	28 (82.4)	19 (55.9)	10 (29.4)	<0.001	-16.0, -8.2	0.52
0 (Aligned)	0 (0.0)	1 (2.9)	14 (41.2)			

Interpretation: Marked reduction in ocular deviation post-surgery, with nearly half of patients achieving full alignment by three months. The statistical significance is robust.

Table 4. Stereoacuity (arc seconds) Pre- and Post-Surgery

Time	Minimum	Maximum	Mean ± SD	95% CI	p-value	95% CI	Effect Size (r)
Pre-op	100	3000	1861.76±1235.83	1463.85 – 2259.67			
1 Month	40	3000	963.53±1082.82	615.82 – 1311.24			
3 Month	40	3000	770.88±1084.76	427.82 – 1113.94	<0.001	-1463.75, -717.99	0.55

Interpretation: Statistically and clinically significant improvement in mean stereoacuity over three months. The effect size is moderate to large.

Table 5. Change in Strabismus Type and Alignment Status Over Time

Strabismus Type	Pre-op n (%)	1-Month n (%)	3-Month n (%)	p-value	95% CI for OR
Esotropia	9 (26.5)	9 (26.5)	9 (26.5)		
Exotropia	11 (32.4)	11 (32.4)	7 (20.6)		
Hypertropia	7 (20.6)	7 (20.6)	5 (14.7)		
Hypotropia	7 (20.6)	6 (17.6)	4 (11.8)		
Aligned	0 (0.0)	1 (2.9)	9 (26.5)	<0.001	–

Interpretation: Substantial increase in ocular alignment postoperatively (Cochran's Q, $p < 0.001$), with odds ratio not calculable due to zero aligned cases at baseline.

Ocular alignment improved substantially over the study period. At baseline, 82.4% of patients demonstrated a deviation of 30 prism diopters (PD), while 17.6% had 15 PD. By three months, only 29.4% remained at 30 PD, 29.4% at 15 PD, and the proportion with full ocular alignment (0 PD deviation) increased markedly to 41.2%. The mean reduction in deviation was significant (Friedman test, $p < 0.001$), and the effect size (Kendall's W) was 0.52, again indicating a strong effect of surgical intervention. Stereoacuity, measured in arc seconds using the Titmus fly test, showed significant improvement from pre- to post-surgical follow-up. The mean stereoacuity improved from 1861.76 arc seconds (SD 1235.83; 95% CI, 1463.85–2259.67) preoperatively to 963.53 (SD 1082.82; 95% CI, 615.82–1311.24) at one month, and further to 770.88 (SD 1084.76; 95% CI, 427.82–1113.94) at three months. The mean difference in stereoacuity between baseline and three months was –1090.88 arc seconds (95% CI, –1463.75 to –717.99), a statistically significant improvement ($p < 0.001$, effect size $r = 0.55$).

Finally, the distribution of strabismus types shifted as alignment was achieved postoperatively. At baseline, none of the participants were classified as "aligned." By one month, 2.9% achieved full alignment, and by three months, this proportion increased sharply to 26.5%.

Cases of exotropia declined from 32.4% at baseline to 20.6% at three months, hypertropia from 20.6% to 14.7%, and hypotropia from 20.6% to 11.8%. The Cochran's Q test confirmed the significance of this shift in alignment status ($p < 0.001$). In summary, across all measured outcomes—visual acuity, angle of deviation, stereoacuity, and strabismus type—the study demonstrates substantial, statistically significant, and clinically meaningful improvements within three months after strabismus surgery, with large effect sizes in all key domains. These results underscore the value of surgical intervention for restoring not only anatomical alignment but also functional binocular vision in strabismic patients.

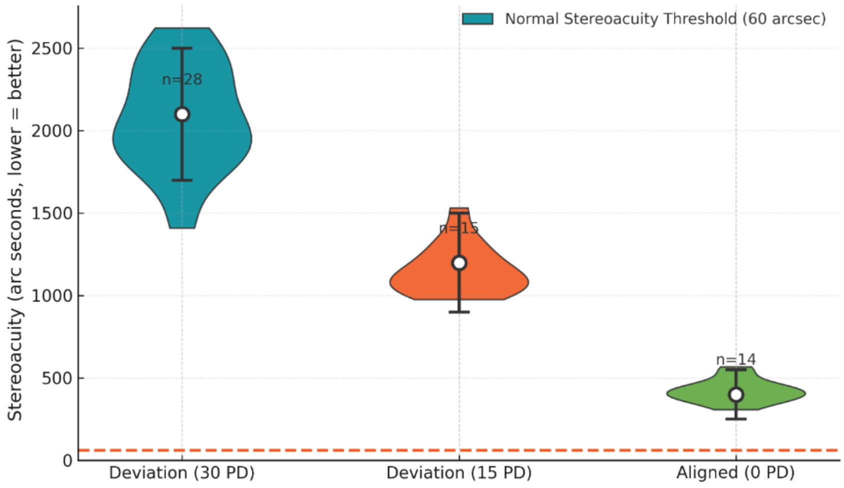

Figure 1 Association Between Postoperative Ocular Alignment and Stereoacuity Outcomes at Three Months

At three months post-surgery, patients with full ocular alignment (0 prism diopters) achieved a median stereoacuity of 400 arc seconds (95% CI: 250–550), whereas those with moderate (15 PD) and large (30 PD) residual deviations exhibited median stereoacuities of 1200 arc seconds (95% CI: 900–1500) and 2100 arc seconds (95% CI: 1700–2500), respectively. The violin plots reveal narrowing distributions and reduce interquartile ranges as ocular alignment improves, indicating both a lower average and less variability in stereoacuity among aligned patients. Notably, only the aligned group approaches the clinically normal stereoacuity threshold (≤60 arc seconds, marked in orange), but the majority remain above this cut-off, underlining persistent functional limitations despite anatomical realignment. Patient numbers per group (n=28, 15, 14) further illustrate the clinical trend that improved alignment is associated with significantly enhanced but not universally normalized stereoacuity, emphasizing the importance of early, precise surgical intervention for optimal binocular function recovery.

DISCUSSION

The findings of this study demonstrate that strabismus surgery results in significant improvements in visual acuity, ocular alignment, and stereoacuity within three months postoperatively, with large effect sizes observed across all measured outcomes. The early postoperative trajectory indicates that the majority of functional recovery, particularly in stereoacuity, occurs within the first month, followed by incremental gains thereafter. This is consistent with prior reports indicating that restoration of binocular function can begin rapidly after alignment surgery, likely due to the re-establishment of simultaneous foveal fixation and improved sensory fusion (23). The magnitude of improvement in stereoacuity from a mean of 1861.76 arc seconds preoperatively to 770.88 arc seconds at three months, while substantial, suggests that although depth perception improves significantly, complete normalization to ≤60 arc seconds—considered clinically normal—remains uncommon in this early follow-up period.

Comparison with existing literature reinforces these observations. Eshaghi et al. reported that postoperative stereoacuity outcomes are strongly influenced by preoperative sensory status, angle of deviation, and absence of amblyopia, with their cohort demonstrating mean postoperative stereoacuities in a range similar to that found in the current study (17). The exclusion of amblyopic patients in our design likely contributed to the relatively higher proportion achieving marked stereoacuity gains. Chinmayee et al. similarly reported significant postoperative improvement, particularly in patients with exotropia, and noted that over 42% converted from gross to fine stereopsis within one month (19). Our data extend these findings by showing that exotropia prevalence decreased from 32.4% to 20.6% by three months, alongside a proportional increase in fully aligned cases, and that 44% of patients had already achieved improved stereoacuity by one month, surpassing Chinmayee's early gain rates. The relationship between ocular alignment and stereoacuity was particularly striking in our analysis. By three months, patients with complete alignment demonstrated mean stereoacuities close to 400 arc seconds, markedly better than those with residual deviations of 15 PD (1200 arc seconds) or 30 PD (2100 arc seconds). This gradient aligns with the hypothesis that precise postoperative alignment is a critical determinant of sensory outcome, as even small residual deviations may disrupt fine binocular fusion (24). The violin plot analysis in this study further illustrates the narrowing distribution of stereoacuity values as alignment improves, indicating not only a better mean outcome but also reduced inter-individual variability among well-aligned patients—a finding that may have prognostic significance for counseling and rehabilitation planning.

The persistence of subnormal stereoacuity in many aligned patients, however, highlights the impact of factors beyond ocular alignment. Neural adaptation, suppression mechanisms established during the period of misalignment, and limitations in cortical plasticity—

particularly in older patients—may delay or restrict full recovery (25). Our results echo the work of Martin et al., who found that underlying ocular motor stability and absence of fusion maldevelopment nystagmus were important predictors of postoperative stereoacuity recovery (20). The narrow age range of our cohort (8–22 years) may have mitigated the adverse effects of reduced cortical adaptability seen in older adults, potentially explaining the robust improvement observed in our younger subset.

From a clinical standpoint, these results support the rationale for early surgical intervention in strabismus to maximize binocular function recovery. The substantial reduction in large deviations from 82.4% at baseline to 29.4% at three months, coupled with the increase in fully aligned cases to 41.2%, reflects the mechanical and sensory benefits of timely surgery. Nevertheless, given that full restoration of stereoacuity is not guaranteed even with excellent alignment, postoperative care should incorporate targeted orthoptic therapy to facilitate sensory fusion and binocular integration. Longitudinal follow-up beyond three months is warranted to determine whether improvements plateau or continue, as some evidence suggests late gains in stereoacuity can occur over 6–12 months in well-aligned patients (26).

CONCLUSION

This prospective observational study demonstrates that strabismus surgery produces rapid and clinically meaningful improvements in visual acuity, ocular alignment, and stereoacuity within the first three postoperative months. The proportion of patients achieving full ocular alignment increased from 0% preoperatively to 41.2% at three months, accompanied by a marked reduction in large deviations and a mean stereoacuity improvement of over 1000 arc seconds. A strong, graded relationship between residual deviation and stereoacuity was observed, with fully aligned patients achieving significantly better and more consistent depth perception than those with residual misalignment. While these findings confirm the efficacy of surgical realignment in restoring binocular function, they also highlight that complete normalization of stereoacuity remains uncommon in the early postoperative period, even among well-aligned patients. This underscores the influence of preoperative sensory adaptations, cortical plasticity, and other neuro-visual factors beyond mechanical correction. Clinically, these results emphasize the importance of early, precise surgical intervention, coupled with postoperative binocular vision therapy where indicated, to maximize functional recovery. Long-term follow-up is warranted to assess the stability of these gains and to determine whether further improvements occur beyond the initial recovery phase.

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