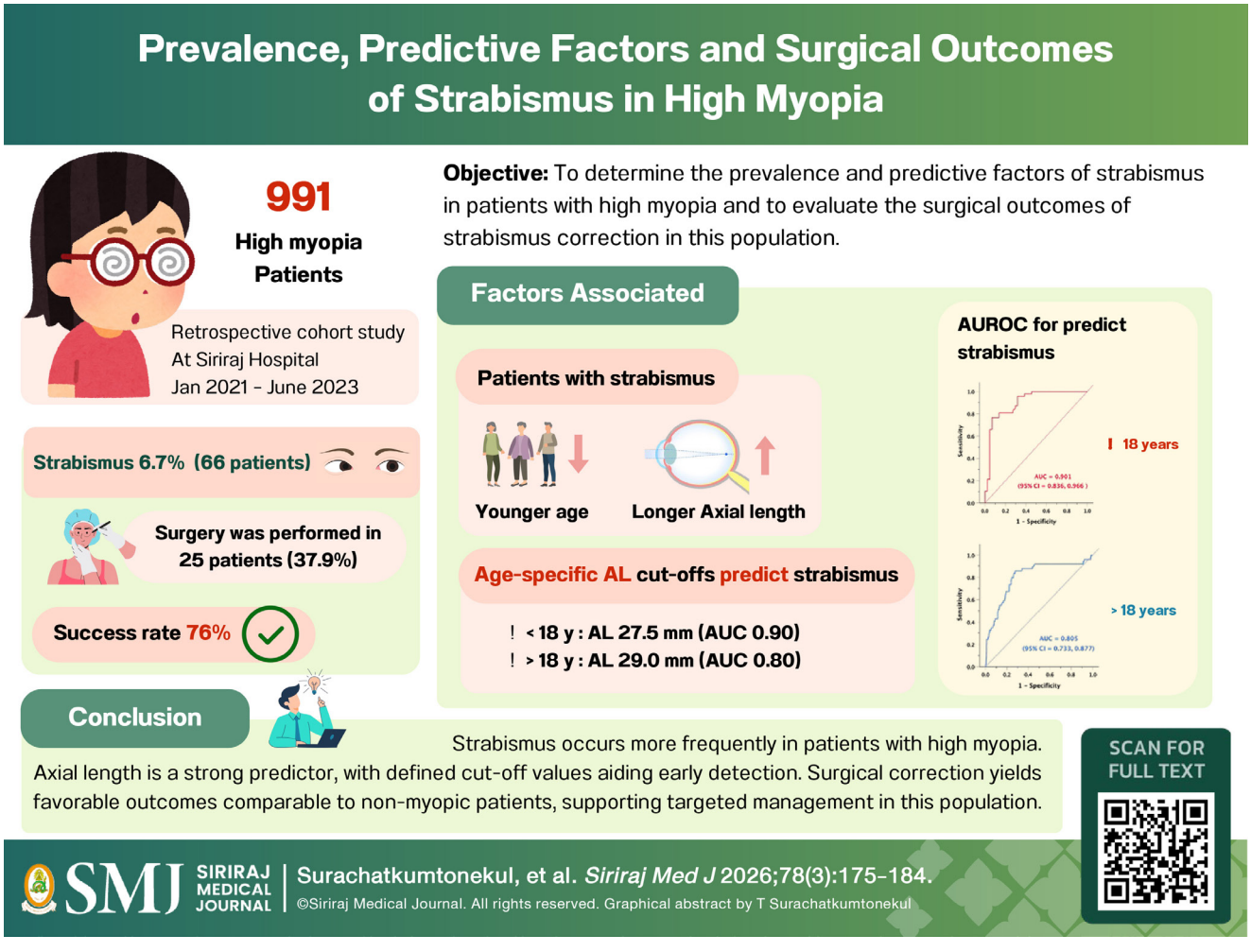
Prevalence, Predictive Factors, and Surgical Outcomes of Strabismus in High Myopia

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ABSTRACT

Objective: To determine the prevalence and predictive factors of strabismus in patients with high myopia and to evaluate the surgical outcomes of strabismus correction in this population.

Materials and Methods: This retrospective cohort study included 991 patients with high myopia (1,880 eyes) who attended Siriraj Hospital between January 2021 and June 2023. High myopia was defined as a spherical equivalent (SE) ≤ -5.0 diopters or an axial length (AL) ≥ 26.5 mm. Collected data included demographics, visual acuity, refractive error, axial length, strabismus type, and surgical outcomes. Surgical success was defined as postoperative alignment within 8 prism diopters (PD) at the 8-week follow-up. ROC curve analysis was performed to determine optimal AL cut-off values for predicting strabismus.

Results: Strabismus was identified in 6.7% (66/991) of patients. The mean SE and AL were -11.41 ± 4.87 D and 28.35 ± 2.06 mm, respectively. Patients with strabismus were younger and had longer AL compared to those without strabismus ($p < 0.01$). ROC analysis showed optimal AL thresholds of 27.5 mm for patients ≤18 years and 29.0 mm for patients >18 years, demonstrating high sensitivity, specificity, and predictive accuracy (AUC = 0.90 and 0.80, respectively). Surgical intervention was performed in 25 patients (37.9%), achieving a success rate of 76%.

Conclusions: Strabismus is more prevalent in individuals with high myopia than in the general population. Axial length is a strong predictor, and defined cut-offs can guide early detection. Surgical outcomes are favorable and comparable to those in non-myopic patients, supporting targeted management strategies in this population.

Keywords: Myopia; strabismus; prevalence; predictive value of tests; predictive factors; ophthalmologic surgical procedures (Siriraj Med J 2026;78(3):175-184)

INTRODUCTION

Myopia, also known as nearsightedness, is a condition where distant objects appear blurry, while near objects remain clear. The World Health Organization defines myopia as a spherical equivalent (SE) of less than or equal to -0.5 diopters (D), and high myopia as an SE of -5.0 D or lower.[1-3] As the global prevalence of myopia continues to rise, it is projected that by 2050, nearly 9.8% of the world's population, or approximately 938 million individuals, will have high myopia.[2,3,6] High myopia is associated with several ocular pathologies, including retinal breaks, retinal detachment, myopic macular degeneration, glaucoma, and strabismus.[4,5]

Strabismus, or misalignment of the eyes, has an estimated prevalence of 2.5-2.9% in the general population, though rates vary by age, ethnicity, and geographic region.[7] In individuals with high myopia, strabismus occurs more frequently due to anatomical changes in the eye, particularly the elongation of the globe. Studies have shown increased prevalence of strabismus among high myopia patients compared to the general population, with studies showing varying results depending on the severity of myopia.[8]

The relevance of understanding this relationship is profound. Identifying predictive factors for strabismus in high myopia could lead to better preventive strategies, earlier interventions, and more targeted treatments, potentially reducing the burden of visual impairment and improving surgical outcomes. Additionally, a better understanding of these factors could inform both clinicians and patients on the prognosis and management of strabismus in the context of high myopia.

This study aims to investigate the prevalence of strabismus in patients with high myopia, identifying predictive risk factors and evaluating surgical outcomes for strabismus correction in this patient group. In particular, we aim to examine how axial length (AL) serves as a key predictive factor for the development of strabismus in high myopia patients, with particular attention to age and refractive error as potential influencing factors.

MATERIALS AND METHODS

Study design

This investigation was a retrospective cohort study conducted at Siriraj Hospital between January 2021 and June 2023. The study was approved by the Siriraj Institutional Review Board (COA No. Si 751/2023) and adhered to the tenets of the Declaration of Helsinki. The sample size was calculated using the formula for estimating an infinite population proportion. The expected prevalence (P) of strabismus in high myopia was obtained from a previous study by *Tanaka et al.* A Z value of 1.96 was applied for a 95% confidence level, with an expected proportion (P) of 0.182 and a precision (d) of 0.025, resulting in a

required sample size of **916 participants**. To account for potential missing data or dropouts, an additional 10% was included, resulting in a total sample size of **1,008 participants**. The inclusion criteria consisted of patients diagnosed with high myopia, defined as spherical equivalent (SE) of -5.0 diopters (D) or less, or an axial length (AL) of 26.5 mm or greater. All participants underwent a detailed ophthalmic evaluation by an ophthalmologist, which included testing for best corrected visual acuity (BCVA), refractive error measurement, assessment of axial length, and evaluation of ocular alignment.

Patient selection

Patient data were collected through a retrospective chart review. Individuals diagnosed with high myopia were identified using the ICD-10 code H44.2. During the study period, 1,676 patients were initially identified. Subsequently, patients who did not meet the inclusion criteria or had incomplete clinical data were excluded from the analysis. A total of 991 patients (1,880 eyes) with high myopia were included in this study. The inclusion process involved a review of medical records from Siriraj Hospital. The patients were assessed for demographic data such as age, sex, and clinical characteristics including BCVA, refractive error, and axial length. Particular attention was given to strabismus diagnoses and type of strabismus (e.g., esotropia, exotropia, etc.).

Strabismus assessment

Strabismus was defined as any clinically diagnosed ocular misalignment. Strabismus type was classified based on the direction of deviation: horizontal (esotropia or exotropia), vertical (hypotropia or hypertropia), or combined horizontal and vertical strabismus. The degree of deviation was measured in prism diopters (PD) using standard clinical methods.

Surgical treatment

Strabismus surgery was performed in 25 cases (37.9%). Most underwent horizontal muscle recession and resection (24 cases), and one patient underwent muscle transposition. Surgical success was defined as postoperative ocular alignment within 8 prism diopters at the 8-week follow-up.

Outcome measures

The primary outcome was the prevalence of strabismus among patients with high myopia. Secondary outcomes included the relationship between axial length and strabismus, the effectiveness of strabismus surgery, and the correlation between axial length measurements and age subgroups (≤ 18 years vs. >18 years). Surgical success was determined by postoperative alignment within 8 prism diopters (PD) at the 8-week follow-up.

Statistical analysis

Descriptive statistics were used to summarize demographic and clinical data of the participants. Categorical variables were presented as frequencies and percentages, while continuous variables were summarized using means and standard deviations (SD). Comparisons between the strabismus and non-strabismus groups were performed using either the two-sample t-test or the Mann–Whitney U test, depending on data distribution. Receiver Operating Characteristic (ROC) curve analysis was utilized to assess the diagnostic accuracy of axial length as a predictor of strabismus. The optimal cut-off values for axial length, in terms of sensitivity and specificity, were determined for predicting strabismus in high myopia patients. A p-value of less than 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS Statistics version 29.0.0 (IBM Corp., USA).

RESULTS

Demographic and clinical data

A total of 991 patients (1,880 eyes) were included in the analysis, with a mean age of 45.80 ± 19.80 years. Among these, 664 (67.0%) were female. Most participants (89.7%) had bilateral myopia. The mean spherical equivalent (SE) was -11.41 ± 4.87 D, and the mean axial length (AL) was 28.35 ± 2.06 mm. Table 1 presents a summary of the demographic data for the study cohort.

Prevalence of strabismus

Among the 991 patients, 6.7% (95% CI = 5.2% to 8.4%) were diagnosed with strabismus, and nine patients with strabismus (13.64%) were identified as having Heavy Eye Syndrome (HES). The most frequently observed type of strabismus was exotropia (47.0%), followed by esotropia (42.4%) and a combination of horizontal and vertical strabismus (6.0%). Only a small percentage of patients had vertical strabismus (4.5%), with hypertropia and hypotropia being the least common (Table 2).

Comparison of strabismus and non-strabismus groups

Table 1 compares the clinical characteristics of patients with and without strabismus. Patients in the strabismus group were significantly younger than those in the non-strabismus group (29.40 ± 22.20 years vs 47.00 ± 19.10 years) ($p < 0.01$). Furthermore, the axial length in the strabismus group was also significantly longer than in the non-strabismus group (29.78 ± 0.21 mm vs. 28.11 ± 0.64 mm, $p < 0.01$).

TABLE 1. Demographic data (Total number = 991 subjects, 1,880 eyes).

Characteristics of 991 patients	
Sex	
Female, n (%)	664 (67.0)
Laterality	
Bilateral, n (%)	889 (89.7)
Age (years), (Mean ± SD)	45.8 ± 19.8
Prevalence of strabismus in high myopia, n (%)	66 / 991 = 6.7% (95% CI = 5.2%–8.4%)

Characteristics of 1,880 eyes	n (eyes)	
BCVA (logMAR), mean ± SD	1,854	0.80 ± 0.24
Spherical equivalent (D), median (IQR)	1,716	-10.25 (-8.00, -14.00)
Axial length (mm), mean ± SD	848	28.30 ± 1.87

Comparison between strabismus and non-strabismus groups

Characteristics	n	Number (%) Strabismus (n = 66)	No Strabismus (n = 925)	p -value
Sex				
Male	327	24 (7.3)	303 (92.7)	0.55
Female	664	42 (6.3)	622 (93.7)	
Laterality				
Unilateral	102	7 (6.9)	95 (93.1)	0.93
Bilateral	889	59 (6.6)	830 (93.4)	
Age (years), (Mean ± SD)	991	29.4 ± 22.2	47.0 ± 19.1	<0.01

Table 3 presents the comparison of visual acuity, spherical equivalent, and axial length. The strabismus group had a mean axial length of 29.78 ± 0.21 mm, which was significantly longer than the non-strabismus group's mean of 28.11 ± 0.64 mm ($p < 0.01$). Additionally, the spherical equivalent was more myopic in the strabismus group (SE = -11.75 ± 4.74 D) compared to the non-strabismus group (SE = -10.13 ± 4.84 D); However, this difference was not statistically significant ($p = 0.87$).

ROC curve analysis

Receiver Operating Characteristic (ROC) curve analysis evaluated the diagnostic ability of axial length for predicting the presence of strabismus. In patients aged ≤18 years, the optimal axial length threshold was 27.5 mm, with an AUC of 0.90, a sensitivity of 80.9%, and a specificity of 75% (Fig 1). For patients older than 18 years, the optimal cut-off value for axial length was 29.0 mm, with an AUC of 0.80, sensitivity of 85.7%, and a specificity of 70.2% (Fig 2). These results indicate that axial length is a reliable predictor of strabismus, with the highest diagnostic accuracy achieved at these cut-off points for both age groups [see Additional file 1].

Surgical outcomes

Surgical intervention was performed in 25 patients (37.9%), including 24 horizontal recession and resection procedures and one muscle transposition. The overall surgical success rate, defined as postoperative alignment within 8 prism diopters (PD), was 76% (Table 4). The

TABLE 2. Clinical characteristics of the strabismus group.

Characteristics	Number (%)
Strabismus type	
Horizontal	
Esotropia	28 (42.4)
Exotropia	31 (47.0)
Vertical	
Hypotropia	0
Hypertropia	3 (4.5)
Horizontal with Vertical	
Exotropia with Hypertropia	2 (3.0)
Esotropia with Hypertropia	1 (1.5)
Esotropia with Hypotropia	1 (1.5)
Deviation (PD), Median (IQR)	
Horizontal	25 (16, 40)
Vertical	10 (5, 20)
Treatment	
Observe	41 (62.1)
Surgery	25 (37.9)

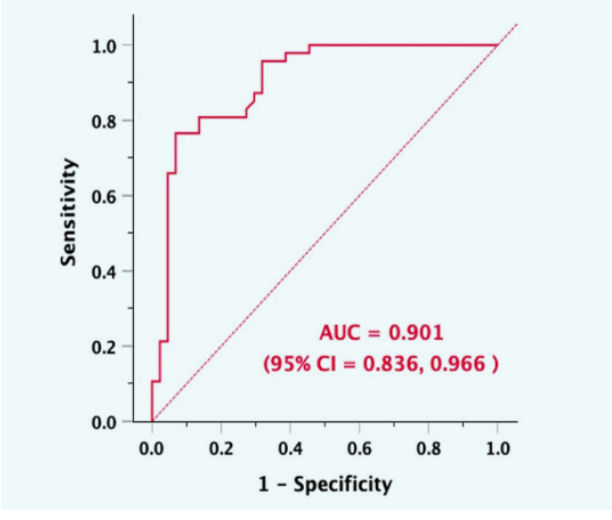


Fig 1. Receiver operating characteristic (ROC) curve for predicting strabismus in high myopia, Age ≤ 18 years, using axial length.

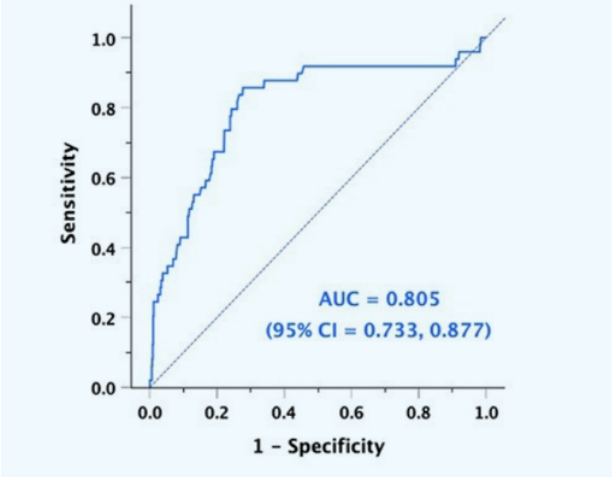


Fig 2. Receiver operating characteristic (ROC) curve for predicting strabismus in high myopia, Age > 18 years, using axial length.

TABLE 3. Comparison of clinical parameters between strabismus and non-strabismus groups.

Parameters	Strabismus		No Strabismus		p-value
	n (eyes)	value	n (eyes)	value	
BCVA (logMAR), mean ± SD					
≤18 years	72	0.74 ± 0.41	227	0.70 ± 0.43	0.72*
>18 years	43	0.82 ± 0.35	1,512	0.82 ± 0.41	0.68*
Total	115	0.62 ± 0.46	1,739	0.84 ± 0.42	0.43*
Spherical equivalent (D), median (IQR)					
≤18 years	67	-12.00(-15.50, -8.50)	179	-11.00(-15.00, -8.75)	0.82†
>18 years	48	-11.00(-15.38, -7.25)	1,422	-10.00(-14.00, -7.75)	0.69†
Total	115	-11.25(-15.50, -8.00)	1,601	-10.25(-14.00, -8.00)	0.10†
Axial length (mm), mean ± SD					
≤18 years	47	29.13 ± 1.77	44	26.36 ± 1.60	<0.01*
>18 years	49	30.40 ± 2.11	708	28.22 ± 1.72	<0.01*
Total	96	29.78 ± 0.21	752	28.11 ± 0.64	<0.01*

* 2-sample t-test

† Mann-Whitney U test

TABLE 4. Surgical details and outcomes in patients with strabismus (n=25).

Characteristics	Number (%)
History of Previous strabismus surgery	
Yes	6 (24.0)
No	19 (76.0)
Type of surgery	
Recession	11 (44.0)
Resection	5 (20.0)
Combined (recession + resection)	6 (24.0)
Muscle transposition	1 (4.0)
Combined muscle surgery with intraoperative chemodenervation	2 (8.0)
Surgical outcome success	
Yes	19 (76.0)
No	6 (24.0)

Parameters, (Mean ± SD)	Pre-operative	Post-operative	p-value
BCVA (logMAR)	0.50 ± 0.48	0.51 ± 0.55	0.94
Spherical equivalent (D)	-11.75 ± 4.74	-10.13 ± 4.84	0.87
Horizontal deviation (PD)	33.61 ± 7.02	4.67 ± 16.33	<0.01

mean preoperative deviation improved significantly from 33.61 ± 7.02 to 4.67 ± 16.33 PD postoperatively ($p < 0.01$). There were no significant variations in best-corrected visual acuity (BCVA) or spherical equivalent post-surgery.

Subgroup analysis

In the age-based subgroup analysis, patients ≤18 years had a significantly shorter mean axial length compared to those >18 years old (29.13 ± 1.77 mm vs. 30.40 ± 2.11 mm, $p < 0.01$). However, the prevalence of strabismus was found to be higher in the younger cohort, suggesting that age plays a significant role in the development of strabismus in high myopia.

DISCUSSION

In this study, the prevalence of strabismus among patients with high myopia was 6.7%, which is notably higher than the prevalence in the general population (1.42% to 2.15%).[9-11] This finding is consistent with previous research, including *Tanaka et al.*, who also reported a high prevalence of strabismus in high myopia, especially horizontal strabismus.[8] The higher prevalence noted in our study could be due to anatomical alterations linked to high myopia, such as increased axial length and globe elongation, which can lead to altered eye muscle function and misalignment.[12]

The higher prevalence of strabismus in younger patients may be partly due to the immaturity of binocular function during childhood. When combined with high myopia, this may lead to reduced visual acuity, which can increase the risk of developing amblyopia. In younger individuals, factors such as immature binocular function, amblyopia, axial length elongation, and changes in the soft tissues surrounding the globe may contribute to ocular misalignment.[13] On the other hand, in older individuals, high myopia may be a result of pathological myopia, which involves progressive axial elongation and ongoing globe enlargement, resulting in significantly greater axial length compared to younger individuals. This continued growth may contribute to more severe forms of ocular misalignment in older adults. Pathological myopia is associated with multiple ocular complications, such as retinal detachment, macular degeneration, and strabismus, due to the continuous elongation of the eye, affecting both the visual system and ocular muscle function.[14]

Our findings reinforce the idea that axial length is a key factor in the development of strabismus, with longer axial lengths being more prevalent. This finding aligns with the work of other researchers, including *Jonas et al.*, who also found that longer axial length was a key factor in the pathophysiology of strabismus in high myopic eyes.[4]

Predictive factors for strabismus

Axial length emerged as a strong predictor of strabismus in high myopia, with cut-off values of 27.5 mm for individuals aged ≤18 years and 29.0 mm for those older than 18 years. This is in line with previous research by *Nakao et al.*, who reported that an axial length greater than 28.0 mm in high myopia patients was linked to a higher risk of developing strabismus.[15] The ROC curve analysis conducted in our study further validates axial length as a reliable diagnostic tool for predicting strabismus in high myopia patients, demonstrating high sensitivity and specificity, particularly among younger patients.

In addition to axial length, our study revealed that younger age was also linked to an increased likelihood of strabismus. This result aligns with the findings of *Tanaka et al.*, who observed that children with high myopia were more likely to develop strabismus than adults.[8] Younger patients may have a higher likelihood of developing strabismus due to ongoing development of ocular structures and the pronounced impact of axial elongation during this period.

Strabismus surgery outcomes

The surgical success rate in our study, defined as a postoperative alignment within 8 prism diopters (PD), was 76%. This result is comparable to other studies on strabismus surgery in high myopia patients, including those by *Kampanartsanyakorn et al.*, who reported a similar success rate for horizontal strabismus surgery.[17] The fact that our study's surgical success rate mirrors those of normal refractive strabismus surgeries indicates that high myopia-related strabismus can achieve similar surgical outcomes, provided that appropriate surgical techniques are used.

Interestingly, our study found that patients who underwent surgery had a significant reduction in horizontal deviation (from 33.61 ± 7.02 PD preoperatively to 4.67 ± 16.33 PD postoperatively). This also aligns with the findings of *Yetkin et al.*, who noted that horizontal strabismus surgeries in high myopic patients resulted in significant improvements in alignment.[16] Despite the promising surgical outcomes, it is important to recognize that surgical success may be influenced by several factors, including preoperative strabismus angle, muscle strength, and the presence of other ocular conditions such as amblyopia or anisometropia.[18]

All patients with unsuccessful surgical outcomes had a spherical equivalent more myopic than −9.50 D, indicating that they likely had substantially greater axial elongation than average. Because currently available surgical dosage tables are largely derived from populations with normal axial length, they may underestimate the dose required in this subgroup. In patients with markedly increased axial length, defined as greater than 27.5 mm, or with very high myopia, consideration should be given to increasing the surgical dose or other surgical procedures in future practice.

Anatomical mechanisms of strabismus in high myopia

Strabismus in high myopia is believed to arise primarily from several anatomical changes linked to axial elongation. One key mechanism is the displacement of the extraocular muscles as the globe elongates, leading to changes in muscle paths and mechanical function.[15,19-24] Prior studies by *Yamaguchi et al.* and *Yokoyama et al.* suggest that lengthening of the eye and the resulting shifts in muscle positioning can impair the balance of ocular muscle forces, contributing to strabismus development.[12,20]

In addition to muscle path changes, globe displacement and changes in the pulley system of the eye have also been suggested to be contributing factors in the development of strabismus in high myopia. These anatomical alterations are further exacerbated by visual impairment and the need for accommodation, which may put additional strain on the ocular muscles, leading to misalignment.[21]

Our findings further support this anatomical and pathophysiologic framework and are consistent with the mechanisms underlying Heavy Eye Syndrome (HES), a condition traditionally associated with extreme axial myopia. HES is characterized by superotemporal globe prolapse relative to the superior and lateral rectus muscles, resulting in severe esotropia and hypotropia. Previous studies have shown that in HES, the lateral rectus (LR) is displaced at a sharp angle of 179.9° ± 30.8° when compared to the superior rectus (SR), reflecting the mechanical displacement of the extraocular muscles as a result of axial elongation.[25] Although orbital imaging was not performed in our study, the strong association between longer axial length and increased strabismus prevalence observed in our cohort is consistent with the mechanical displacement of extraocular muscles described in HES. Previous MRI-based studies by Yamaguchi, Demer, and colleagues have demonstrated that progressive axial elongation leads to distortion of the muscle cone and degeneration of the LR–SR band, culminating in ocular misalignment typical of HES. Our results, therefore, represent the epidemiologic and clinical counterpart of these anatomic mechanisms, suggesting that high axial length may serve as an early indicator of the same pathologic process that, in its advanced form, manifests as Heavy Eye Syndrome.[12,21,26]

Sagging eye syndrome (SES) may also represent a relevant pathophysiologic consideration in this population, particularly among older patients. SES is characterized by age-related degeneration and attenuation of the lateral rectus–superior rectus (LR–SR) band, resulting in inferior displacement of the lateral rectus pulley and a divergence-insufficiency pattern of esotropia. Studies comparing the displacement angles in SES revealed that the LR was displaced at a shallower angle of 104° ± 11° compared to the SR, suggesting a less severe degree of displacement than that seen in HES.[25] Unlike heavy eye syndrome, which is typically associated with marked axial elongation and superotemporal globe prolapse, SES can occur even in eyes without extreme axial myopia and may therefore account for strabismus in selected patients whose axial length measurements are less remarkable. Although our study did not incorporate orbital imaging to differentiate mechanical etiologies, the coexistence of axial elongation and age-related connective tissue changes likely represents a continuum of anatomical alterations that can influence ocular alignment.[21,27]

Understanding these anatomical mechanisms provides a crucial framework for interpreting our findings, emphasizing that early identification of high axial length may help prevent progression to severe mechanical strabismus requiring complex surgical correction.

Limitations

This study has several limitations that warrant consideration. The retrospective design introduces inherent selection bias and restricts the ability to infer causal relationships between axial length and the development of strabismus. Because the study was conducted at a single tertiary referral center, the cohort may include a higher proportion of complex cases, which could limit the generalizability of the findings to other clinical settings. In addition, although axial length emerged as a strong predictor of strabismus, orbital imaging was not routinely performed at Siriraj Hospital because of cost constraints and long waiting times. As a result, orbital imaging was not obtained for all patients, precluding direct assessment of the anatomical mechanisms underlying ocular misalignment, including potential extraocular muscle displacement and features related to Heavy Eye Syndrome and Sagging Eye Syndrome. Collectively, these factors underscore the need for prospective, multicenter

investigations with standardized imaging protocols to more clearly delineate the structural pathways and clinical implications of strabismus in high myopia.

CONCLUSION

The prevalence of strabismus among patients with high myopia was 6.7%, notably higher than that seen in the general population. This emphasizes the elevated risk of strabismus in individuals with high myopia and highlights the need for early identification and intervention. Axial length was identified as a strong predictive factor for strabismus, with cut-off values of 27.5 mm for individuals aged ≤18 years and 29.0 mm for those over 18 years. These findings provide valuable insights into how axial length can be utilized as a diagnostic tool to identify high-risk individuals.

The observed association between increasing axial length and higher strabismus prevalence supports the proposed pathophysiologic continuum of Heavy Eye Syndrome (HES). Progressive globe elongation may initiate subtle extraocular muscle displacement that precedes the severe mechanical misalignment characteristic of HES.

The surgical success rate of 76% observed in this study indicates that strabismus surgery in high myopia patients can achieve results comparable to those seen in non-myopic populations. This reinforces the notion that surgical intervention can be an effective treatment modality for strabismus in high myopia, even though the outcomes may be influenced by factors such as age and preoperative strabismus angle.

Although the findings of this study provide important insights into strabismus in high myopia, the retrospective design and lack of a control group limit the ability to establish a clear cause-and-effect link between axial length and strabismus. Future prospective studies incorporating advanced imaging techniques, such as MRI, to evaluate the anatomical changes in the eye and extraocular muscles, as well as including control groups, will be crucial for further validating these findings and exploring the underlying mechanisms in greater detail.

Data Availability Statement

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

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DECLARATIONS

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Conflict of Interest

The authors declare that they have no competing interests.

Registration Number of Clinical Trial

Not applicable. This was a retrospective study and was not registered as a clinical trial.

Authors' Contributions

Conceptualization and methodology, T.S. ; Investigation, Data collection and Data analysis, P.J. ; Writing-original draft preparation, review and editing, T.S., P.J. ; Supervision, T.S. All authors read and approved the final manuscript.

Use of Artificial Intelligence

During preparation of the manuscript, the authors used Grammarly and ChatGPT 5.2 to refine grammar and enhance readability.

Ethics Approval and Consent to Participate

The study was approved by the Siriraj Institutional Review Board (COA No. Si 751/2023).

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