BMC Ophthalmology

RESEARCH

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Epidemiological insights into complication and outcomes in corneal refractive surgery population: findings from KNHANES 2010–2012

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Abstract

Purpose Epidemiological studies on corneal refractive surgery remain limited, particularly regarding complications such as dry eye disease and refractive error regression, which impact long-term visual outcomes and patient satisfaction. This study aimed to evaluate the demographic and clinical characteristics of individuals with a history of corneal refractive surgery using data from the Korean National Health and Nutrition Examination Survey (KNHANES) 2010–2012.

Methods This cross-sectional study included 595 participants with a self-reported history of corneal refractive surgery. Data on diagnosed dry eye disease, dry eye symptoms, and previous ocular surgeries were collected through structured questionnaires, while ophthalmologic examinations provided information on refractive errors, intraocular pressure, and other ocular conditions. Logistic regression analysis identified factors associated with dry eye disease and symptoms.

Results Dry eye disease and refractive error regression were frequently reported among individuals with a history of corneal refractive surgery. Among participants, 24.2% reported diagnosed dry eye disease, and 33.1% reported dry eye symptoms. Significant myopia (≤ -0.75 D) and significant astigmatism (≤ -0.75 D) were present in 49.4% and 39.7%, respectively. Using the timing of the last ophthalmologic examination as a proxy for time since surgery, results showed a progressive myopic shift in spherical refractive error over time, while the prevalence of dry eye disease and symptoms gradually declined. Female sex (OR = 1.76, 95% CI = 1.05–2.96) and prolonged sun exposure (> 5 h/day, OR = 2.47, 95% CI = 0.96–6.36) were associated with a higher likelihood of diagnosed dry eye disease, while a longer time since surgery was associated with decreased dry eye symptoms. Severe diseases such as cataracts (0.3%), glaucoma (0.5%), and surgically treated retinal disorders (0.2%) were rare.

Conclusions This study provides epidemiological insights into associations between corneal refractive surgery and postoperative outcomes, highlighting dry eye disease and refractive error regression as prevalent findings, while observing that severe complications were rarely reported. Sex and sun exposure were identified as important risk factors for dry eye disease, warranting attention in preoperative counseling and postoperative care. These findings support the need for procedure-specific, longitudinal research to optimize patient outcomes and satisfaction.

Keywords Corneal refractive surgery, Dry eye disease, Refractive error regression, Epidemiology, KNHANES

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Introduction

The increasing prevalence of myopia worldwide has driven the demand for effective and lasting treatments to correct refractive errors [1]. Corneal refractive surgery, including laser-assisted in situ keratomileusis (LASIK) and photorefractive keratectomy (PRK), has emerged as a widely adopted solution for addressing myopia, hyperopia, and astigmatism [2]. These surgical techniques reshape the cornea to improve uncorrected visual acuity, providing patients with a significant reduction in dependency on corrective lenses and enhancing their quality of life. As the myopic population continues to rise, understanding the outcomes and complications of these procedures is increasingly important.

Despite the widespread adoption of corneal refractive surgery, various complications can arise, necessitating thorough preoperative evaluations and postoperative management [3]. Among these complications, dry eye disease and myopic or astigmatic regression are particularly noteworthy [4, 5]. Dry eye disease, often reported as a new or exacerbated symptom after surgery, can lead to discomfort, reduced visual quality, and decreased patient satisfaction. Additionally, myopic or astigmatic regression, wherein refractive errors reemerge over time, poses challenges to long-term surgical success and may require further interventions [6]. Objective demographic and clinical data are crucial for identifying and understanding other potential ocular complications associated with refractive surgery. However, while these issues are widely acknowledged, their prevalence, contributing risk factors, and long-term implications within the broader surgical population remain underexplored.

To date, no large-scale epidemiological study has comprehensively examined the population undergoing corneal refractive surgery. Most existing research has focused on clinical outcomes or complications within specific cases or institutional settings [7], leaving a significant gap in understanding the broader epidemiology of these patients. Insights into their demographic characteristics, ocular histories, and post-surgical complications are essential for developing strategies to enhance patient care and surgical success. Additionally, many studies may be subject to bias, as they rely on postoperative reports directly provided by surgical institutions or surgeons. There remains a lack of objective studies assessing the ocular status of the broader population that has undergone refractive surgery.

The Korean National Health and Nutrition Examination Survey (KNHANES) provides a valuable opportunity to explore the epidemiology of individuals who have undergone corneal refractive surgery [8]. In particular, the 2010–2012 KNHANES survey incorporates dry eye questionnaires and comprehensive ophthalmic examinations, allowing for an in-depth assessment of dry eye disease and refractive error regression [9]. Since small incision lenticule extraction (SMILE) and phakic intraocular lens (IOL) implantation were rarely performed during this period, the dataset primarily reflects outcomes from LASIK and PRK surgeries conducted before that time.

This study aims to assess the prevalence of dry eye disease, refractive error regression, and other ocular conditions among individuals who have undergone corneal refractive surgery in the KNHANES 2010–2012. By analyzing these population-level data, we seek to provide clinically relevant insights that can enhance preoperative counseling, postoperative management, and overall patient care for refractive surgery patients.

Methods

Study design and data source

This cross-sectional study utilized data from the KNHANES conducted between 2010 and 2012. KNHANES is a nationally representative survey designed to assess the health and nutritional status of the Korean population through interviews, physical examinations, and laboratory tests (KNHANES V; available online at https://knhanes.kdca.go.kr/knhanes/eng/main.do) [10]. This project selected all participants randomly from among 192 enumeration districts using stratified sampling in which the following factors were considered: population, sex, age, regional area, and type of residential area. Therefore, this sampling is representative of the population data of the South Korea. For this study, participants who had undergone corneal refractive surgery were identified based on self-reported surgical history. This study was conducted using anonymized data from the publicly available KNHANES dataset, which was approved by the Institutional Review Board (IRB) of the Korea Centers for Disease Control and Prevention (IRB numbers: 2010-02CON-21-C, 2011–02-CON-06-C, and 2012–01-EXP-01-2C). Written informed consent was obtained from all participants prior to their inclusion in the survey. As the study exclusively utilized publicly available data, additional IRB approval was not required. The study complied with the principles outlined in the Declaration of Helsinki, ensuring ethical standards were maintained throughout.

The KNHANES dataset comprehensively collected demographic, socioeconomic, and lifestyle information, including the following key variables: age, sex, residential area, education level, household income, occupation, and sun exposure duration. These variables provide critical context for understanding the population's health outcomes and allow for robust multivariable analyses to

explore associations between these factors and ocular or systemic conditions.

The KNHANES dataset does not include information on the exact timing of corneal refractive surgery. However, it provides data on the timing of the last comprehensive ophthalmologic examination, categorized into five groups: within the past month, between 1 month and 1 year ago, between 1 and 3 years ago, more than 3 years ago, and too long ago to recall. Given that patients typically undergo comprehensive ophthalmologic evaluations both before and after refractive surgery, we assume that the timing of the last examination is closely aligned with the timing of surgery. While this approximation introduces some uncertainty, it serves as a reasonable proxy for estimating the time elapsed since surgery in the absence of direct surgical records.

Study population

Figure 1 illustrates the selection process of the study population from the Korean National Health and Nutrition Examination Survey (KNHANES) dataset for the years 2010 to 2012. Among a total of 23,376 participants during this period, individuals with incomplete ocular surgery history surveys ($N=20,765$) were excluded from the analysis. Of the remaining 2,611 participants with complete ocular surgery history data, 610 individuals reported undergoing corneal refractive surgery. Further exclusions were made among those who had incomplete or missing ophthalmologic examination data ($N=15$), resulting in a final study population of 595 individuals who underwent corneal refractive surgery. The dataset used excluded KNHANES 2009 and earlier data, which lacked dry eye data, and KNHANES 2013 and later data, which lacked detailed eye examination information. This systematic selection ensures the inclusion of individuals with comprehensive ocular surgery history and detailed ophthalmologic examination data for reliable analysis.

Data collection

A detailed ophthalmologic examination was conducted in a mobile clinic equipped with advanced ophthalmic instruments, operated by ophthalmologists affiliated with the Korean Ophthalmological Society (KOS) [11]. To ensure consistency and accuracy, these ophthalmologists received periodic training organized by the KOS National Epidemiologic Survey Committee. The quality of the survey was further monitored and verified by the Korea Disease Control and Prevention Agency (KDCA). The examinations were carried out by these trained professionals, and data were collected using both self-reported questionnaires and direct ophthalmologic evaluations.

The self-reported questionnaires gathered information on participants' history of dry eye disease diagnosis, symptoms of dry eye, and any previous ocular surgeries [12]. To identify clinically diagnosed or self-reported dry eye, participants were asked: "Have you ever been diagnosed with dry eye (in either eye) by a physician?" emphasizing the importance of a clinical diagnosis. Respondents could choose "yes" or "no." They were also asked: "Until now, have you ever experienced dry eye symptoms, such as dryness or irritation in the eye?" to capture self-reported symptoms

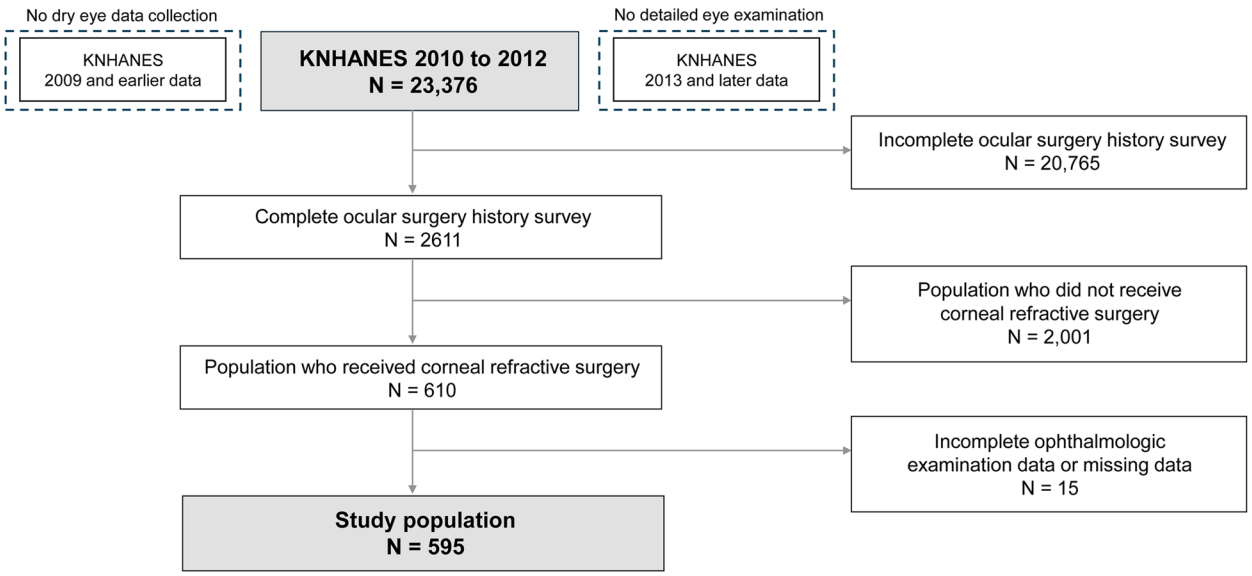

Fig. 1 Flowchart illustrating the selection process of the study population from the Korean National Health and Nutrition Examination Survey (KNHANES) dataset between 2010 and 2012

[13]. Both questions were answered independently for diagnosed dry eye disease and self-reported symptoms, and were analyzed separately, following methodologies from previous studies using the same dataset. Additionally, the inclusion of both diagnosed dry eye disease and self-reported symptoms helps mitigate recall bias, as one question reflects clinical history, while the other captures current or past symptoms. This dual-question approach enhances the reliability of the data by differentiating between objective medical diagnoses and subjective symptom experiences, following methodologies from previous studies using the same dataset.

Ophthalmologic examination data encompassed measurements such as automated refraction (sphere and cylinder), intraocular pressure, and the identification of ocular conditions including cataracts, pterygium, diabetic retinopathy, and age-related macular degeneration. For automated refraction and intraocular pressure, data from one eye were randomly selected for analysis. For ocular diseases, the condition was recorded if it was present in either eye. Regression of refractive error was assessed using automated refraction measurements, with significant regression defined as myopia ≤ -0.75 diopters or astigmatism ≤ -0.75 diopters, a criterion commonly adopted in similar studies [5, 14]. This approach ensured consistency in assessing refractive outcomes across the study population.

Slit-lamp examinations (Haag-Streit model BQ-900; Haag-Streit AG, Koeniz, Switzerland) were performed without dilating the pupil. The crystalline lens was assessed layer by layer, from the anterior to the posterior capsule, to evaluate cataract subtypes and severity. The Lens Opacities Classification System III (LOCS III) was used for grading cataracts, and comparisons were made with standard LOCS III photographs [15]. Cataracts were classified as cortical (LOCS III score $\geq$ C2), nuclear (nuclear opalescence or nuclear color score ≥ 4), or posterior subcapsular (LOCS III score $\geq$ P2). It is worth noting that the absence of pupil dilation may have limited the detection of peripheral lens opacities.

Digital fundus images were captured using a nonmydriatic fundus camera (TRC-NW6S; Topcon) under physiological mydriasis. For each participant, a 45° digital retinal image centered on the fovea was taken for both eyes. Observations on optic nerve structure and retinal pathologies were recorded. Each fundus image underwent a two-step review process: initial grading was conducted on-site by trained ophthalmologists or residents under the guidance of the KOS, and final, detailed grading was performed by retinal specialists from the KOS.

Statistical analysis

Descriptive statistics were employed to summarize the demographic and clinical characteristics of the study population. Continuous variables were reported as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages. Associations between categorical variables, such as dry eye prevalence and demographic characteristics, were analyzed using the chi-squared test. Logistic regression models were applied to identify factors associated with diagnosed dry eye disease and dry eye symptoms. Backward feature selection was performed with entry criteria set at a P-value of 0.05 and removal criteria at a P-value of 0.10. Statistical significance was defined as a P-value < 0.05. All analyses were performed using SPSS software (version 23.0).

Results

Table 1 summarizes the demographic characteristics of the study population who underwent corneal refractive surgery. Among the 595 participants, the majority were female (78.2%, $N=465$), while males accounted for 21.8% ($N=130$). The most represented age group was 31 to 40 years, comprising 47.4% of the population ($N=282$), followed by the 21 to 30 years group (34.5%, $N=205$). In terms of residential distribution, 92.4% of participants resided in urban areas ($N=550$), with only 7.6% living in rural areas ($N=45$). Educational levels were predominantly high, with 71.6% of participants ($N=426$) having attained college-level education or higher, followed by 27.2% ($N=162$) who had completed high school. Household income was stratified into quartiles, with the largest proportion of participants in the highest income quartile (Q4, 47.7%, $N=284$), followed by Q3 (29.6%, $N=176$), Q2 (18.0%, $N=107$), and the lowest income quartile (Q1, 4.7%, $N=28$). Regarding occupation, 38.7% of participants were unemployed (e.g., housewives or students, $N=230$), while 27.4% ($N=163$) were professionals or managers. Other occupational groups included clerks (17.6%, $N=105$), service or sales workers (10.6%, $N=63$), and smaller proportions of workers in agriculture, craft, or elementary occupations.

Figure 2 illustrates the age distribution of the study population who underwent corneal refractive surgery, stratified by sex. Male participants ($N=130$) had a mean age of 33.6 years (SD = 8.4). The age distribution among males is slightly skewed, with most participants concentrated between 20 and 40 years, peaking around the mid-30 s. A smaller number of participants fall into the older age groups, with very few over 50 years. Female participants ($N=465$) had a slightly higher mean age of 34.1 years (SD = 7.4). The distribution among females is more symmetric, with the largest frequency observed

Table 1 Demographics of the study population who received corneal refractive surgery

Variable	Category	N	Percentage (%)
Age	≤ 20 years	6	1.0
	21 to 30 years	205	34.5
	31 to 40 years	282	47.4
	41 to 50 years	86	14.5
	51 to 60 years	12	2.0
	> 60 years	4	0.7
Sex	Male	130	21.8
	Female	465	78.2
Residential area	Rural	45	7.6
	Urban	550	92.4
Education	≤ Elementary school	3	0.5
	Middle school	4	0.7
	High school	162	27.2
	≥ College	426	71.6
House income	Q1 (lowest income)	28	4.7
	Q2	107	18.0
	Q3	176	29.6
	Q4 (highest income)	284	47.7
Occupation	Managers, professional, and related workers	163	27.4
	Clerks	105	17.6
	Service/sales workers	63	10.6
	Agricultural, forestry, and fishery workers	2	0.3
	Craft workers, equipment and machine operation, and assembling workers	19	3.2
	Elementary workers	10	1.7
	Unemployed (housewife, student, etc.)	230	38.7
Sun exposure	≤ 2 h	467	78.5
	2 to 5 h	107	18.0
	> 5 h	21	3.5
Last Ophthalmology examination[a]	within the past 1 month	71	11.9
	Between 1 month and 1 year ago	161	27.1
	Between 1 and 3 years ago	153	25.7
	More than 3 years ago	174	29.2
	Too long ago to recall	36	6.1

[a] In this study, it was used as a proxy to approximate the time since surgery

between 30 and 40 years. While the overall pattern is similar to males, the larger sample size among females provides a more distinct visualization of the peak age group.

Table 2 presents the self-reported ocular conditions and eye examination findings among the study population who underwent corneal refractive surgery. Dry eye disease and refractive error regression were the most reported postoperative complications. Among the participants, 24.2% ($N=144$) reported a history of diagnosed dry eye disease, while 33.1% ($N=197$) reported experiencing dry eye symptoms. The prevalence of prior ocular surgeries in the study population was low. A total of 0.3% ($N=2$) reported a history of cataract surgery (one 61-year-old female and one 68-year-old male), while 0.2% ($N=1$) reported undergoing retinal surgery (a 30-year-old male). No participants reported a history of glaucoma surgery. Additionally, 0.5% ($N=3$) of participants (women aged 47, 49, and 61) were using glaucoma medications at the time of the survey. In terms of ophthalmologic examination findings, the mean spherical equivalent refraction was −0.35 diopters (SD = 0.80), and the mean cylindrical refraction was −0.46 diopters (SD = 0.43). Significant myopia (≤ −0.75 diopters) was observed in 49.4% of the population ($N=294$), and significant astigmatism (≤ −0.75 diopters) was present in 39.7% ($N=236$). The

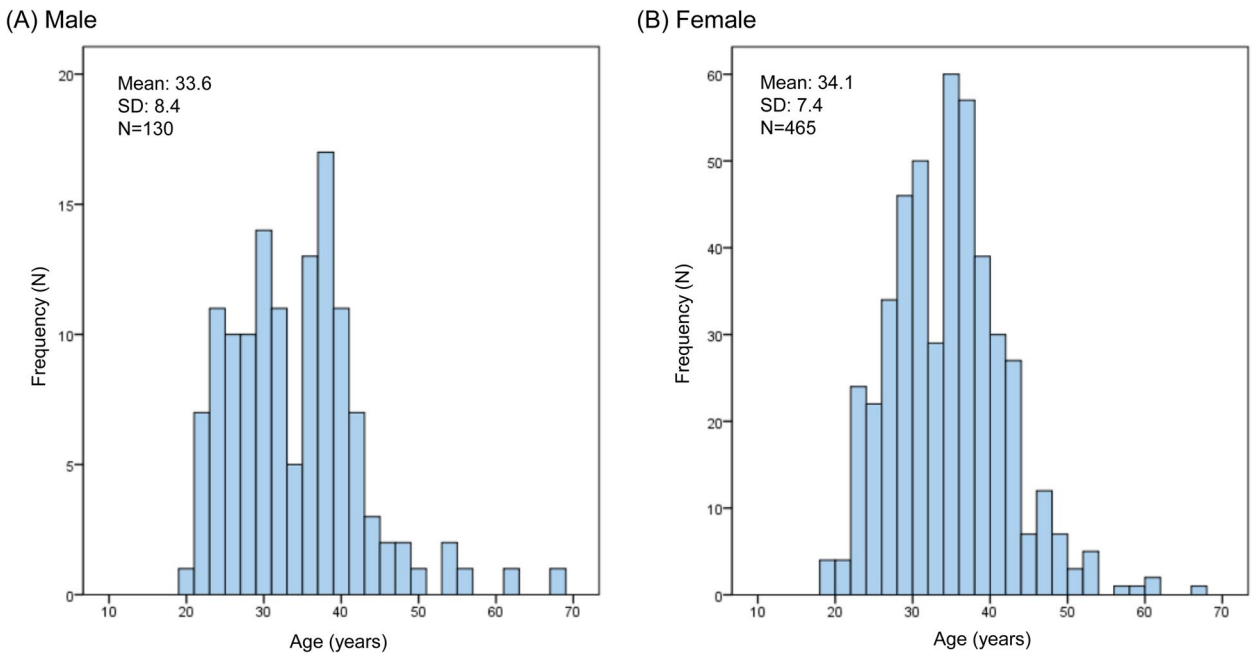

Fig. 2 Age distribution of the study population who underwent corneal refractive surgery, categorized by sex. **A** Male participants ($N=130$) with a mean age of 33.6 years (SD = 8.4). **B** Female participants ($N=465$) with a mean age of 34.1 years (SD = 7.4)

Table 2 Self-reported ocular conditions and eye examination findings among the study population who underwent corneal refractive surgery

Category	Feature	N (%) or Mean ± SD
Self-reported data	History of dry eye diagnosis	144 (24.2)
	Dry eye symptom	197 (33.1)
	History of cataract surgery	2 (0.3)
	History of retinal surgery	1 (0.2)
	History of glaucoma surgery	0 (0.0)
	Glaucoma medication	3 (0.5)
Eye examination	Automated refraction sphere (D)[a]	−0.35 ± 0.80
	Automated refraction cylinder (D)[a]	−0.46 ± 0.43
	Significant myopia (≤ −0.75 D)[b]	294 (49.4)
	Significant astigmatism (≤ −0.75 D)[b]	236 (39.7)
	Intraocular pressure (mmHg)[a]	12.30 ± 2.62
	Cataract	19 (3.2)
	Pterygium	0 (0.0)
	Diabetic retinopathy	1 (0.2)
	Early age-related macular degeneration	3 (0.5)
	Late age-related macular degeneration	0 (0.0)

Abbreviation: D Diopter, *SD* Standard deviation

[a] Values measured from a randomly selected eye

[b] If the condition applies to either eye, it is considered present

mean intraocular pressure was 12.30 mmHg (SD = 2.62). Additional eye conditions identified during examinations included cataracts in 3.2% of participants ($N=19$)

and early-stage age-related macular degeneration in 0.5% ($N=3$). Pterygium, diabetic retinopathy, and late-stage age-related macular degeneration were rare, with negligible prevalence (0.0% to 0.2%).

Figure 3 shows the distribution of refractive error measurements among the study population who underwent corneal refractive surgery. The distribution of spherical equivalent refraction values shows a mean of −0.35 diopters (SD = 0.80). Most participants exhibit values close to emmetropia, with a notable peak around 0 diopters. A smaller proportion of participants have residual myopia (negative values) or hyperopia (positive values), indicating a largely successful correction of refractive errors in most cases. The distribution of cylindrical refraction has a mean of −0.46 diopters (SD = 0.43). The histogram shows a concentration of participants with low levels of residual astigmatism, with a sharp peak near 0 diopters. A smaller subset of participants has higher levels of residual astigmatism, with values extending to −3.00 diopters.

Figure 4 displays the prevalence of diagnosed dry eye disease and dry eye symptoms among the study population who underwent corneal refractive surgery, stratified

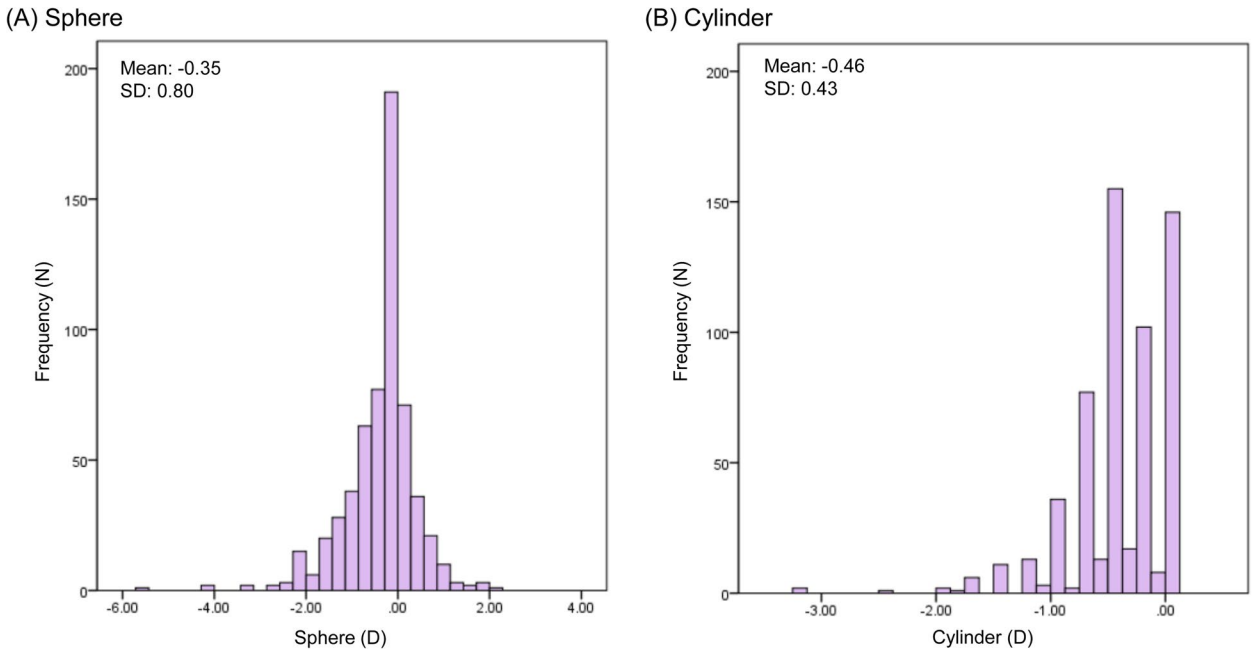

Fig. 3 Distribution of refractive error measurements in the study population. **A** Sphere: The mean spherical refractive error was −0.35 diopters (SD = 0.80). The histogram illustrates the frequency of spherical refractive error values. **B** Cylinder: The mean cylindrical refractive error was −0.46 diopters (SD = 0.43). The histogram depicts the distribution of astigmatic refractive errors

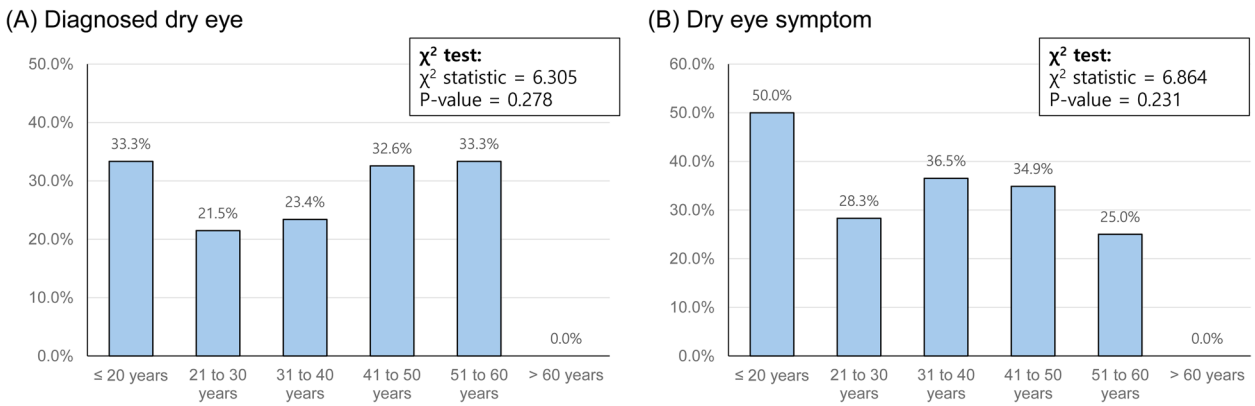

Fig. 4 Prevalence of diagnosed dry eye and dry eye symptoms among the study population who underwent corneal refractive surgery, stratified by age groups. **A** Diagnosed dry eye. **B** Dry eye symptoms. No significant association was observed

by age groups. For diagnosed dry eye disease, the highest prevalence was observed in the age groups ≤ 20 years and 51 to 60 years (33.3% each), while the lowest prevalence was in the 21 to 30 years group (21.5%). The age groups 31 to 40 years and 41 to 50 years reported similar prevalence rates of 23.4% and 32.6%, respectively. No cases of diagnosed dry eye disease were reported in participants over 60 years of age. A chi-squared test revealed no statistically significant association between age group and diagnosed dry eye disease (χ^2 statistic = 6.305, $p = 0.278$). For self-reported dry eye symptoms, participants ≤ 20 years of age reported the highest prevalence of symptoms (50.0%), followed by the 31 to 40 years (36.5%) and 41 to 50 years (34.9%) groups. The prevalence was lower in the 21 to 30 years (28.3%) and 51 to 60 years (25.0%) age groups, with no reported symptoms in participants older than 60 years. Similar to diagnosed dry eye disease, no significant association was found between age group and dry eye symptoms (χ^2 statistic = 6.864, $p = 0.231$).

Table 3 presents the results of the multivariable logistic regression analysis identifying factors associated with diagnosed dry eye disease and dry eye symptoms in the study population who underwent corneal refractive surgery. For diagnosed dry eye disease, females were significantly more likely to report a history of diagnosis compared to males (odds ratio [OR] = 1.76, 95% confidence interval [CI] = 1.05–2.96, $p = 0.033$). Although participants with more than 5 h of daily sun exposure showed an increased likelihood of having a history of diagnosed dry eye (OR = 2.47, 95% CI = 0.96–6.36), this association did not reach statistical significance ($p = 0.061$). Additionally, the time since the last ophthalmologic examination, used as a proxy for the time since surgery, was significantly associated with diagnosed dry eye. Compared to participants who had their last examination within the past month, those who had their last examination more than 3 years ago (OR = 0.30, 95% CI = 0.15–0.57, $p < 0.001$) or could not recall the timing of their last examination (OR = 0.22, 95% CI = 0.07–0.70, $p = 0.011$) were significantly less likely to report a history of diagnosed dry eye. For self-reported dry eye symptoms, female sex was again a significant risk factor (OR = 1.82, 95% CI = 1.15–2.88, $p = 0.010$). The time since the last ophthalmologic examination was

Table 3 Multivariable logistic regression with backward feature selection result for self-reported diagnosed dry eye and dry eye symptom in the study population who received corneal refractive surgery

Dry eye type	Variable	Category	OR (95% CI)[a]	*P*-value
History of dry eye diagnosis	Sex	Male	1.00 (Reference)	-
		Female	1.76 (1.05–2.96)	0.033
	Sun exposure	≤ 2 h	1.00 (Reference)	
		2 to 5 h	0.70 (0.41–1.20)	0.192
		> 5 h	2.47 (0.96–6.36)	0.061
	Last Ophthalmology examination[b]	within the past 1 month	1.00 (Reference)	-
		Between 1 month and 1 year ago	0.72 (0.40–1.32)	0.292
		Between 1 and 3 years ago	0.69 (0.38–1.28)	0.241
		More than 3 years ago	0.30 (0.15–0.57)	< 0.001
		Too long ago to recall	0.22 (0.07–0.70)	0.011
Dry eye symptom	Sex	Male	1.00 (Reference)	-
		Female	1.82 (1.15–2.88)	0.010
	Last Ophthalmology examination[b]	within the past 1 month	1.00 (Reference)	-
		Between 1 month and 1 year ago	0.68 (0.38–1.22)	0.199
		Between 1 and 3 years ago	0.69 (0.39–1.24)	0.218
		More than 3 years ago	0.40 (0.22–0.72)	0.002
		Too long ago to recall	0.25 (0.09–0.68)	0.007
	Significant myopia (≤ –0.75 D)[c]	No	1.00 (Reference)	-
		Yes	1.53 (1.06–2.21)	0.023
	Significant astigmatism (≤ –0.75 D)[c]	No	1.00 (Reference)	-
		Yes	0.70 (0.48–1.01)	0.058

Abbreviation: CI confidence interval, *D* Diopter, *OR* Odds ratio

[a] Odds ratio extracted from variables included in the final model, obtained using backward feature selection with entry *P*-value = 0.05 and removal *P*-value = 0.10

[b] In this study, it was used as a proxy to approximate the time since surgery

[c] If the condition applies to either eye, it is considered present

also significantly associated with symptom prevalence, with lower odds of reporting dry eye symptoms among those whose last examination was more than 3 years ago (OR = 0.40, 95% CI = 0.22–0.72, $p = 0.002$) or too long ago to recall (OR = 0.25, 95% CI = 0.09–0.68, $p = 0.007$), compared to those examined within the past month. Additionally, significant myopia (≤ −0.75 D) was associated with a higher likelihood of reporting dry eye symptoms (OR = 1.53, 95% CI = 1.06–2.21, $p = 0.023$), while significant astigmatism (≤ −0.75 D) showed only a marginal association (OR = 0.70, 95% CI = 0.48–1.01, $p = 0.058$).

Figure 5 illustrates the relationship between the timing of the last ophthalmologic examination, used as a proxy for time since surgery, and refractive error measurements, as well as astigmatism types. The mean spherical refractive error shows a significant worsening trend over time, with a *P*-value for linear trend < 0.001, suggesting progressive myopic regression in patients with longer postoperative periods. The mean cylindrical refractive error remains relatively stable across different time groups, with no significant linear trend ($P = 0.403$), indicating that astigmatism progression may not be strongly associated with time since surgery. The distribution of astigmatism types (with-the-rule [WTR], against-the-rule [ATR], and oblique astigmatism) appears consistent across different time groups, with no statistically significant differences (χ^2 statistic = 6.080, $P = 0.638$).

Figure 6 illustrates the association between the timing of the last ophthalmologic examination, used as a proxy for time since surgery, and key postoperative outcomes, including refractive errors and dry eye disease. The proportion of participants with significant myopia (≤ −0.75 D) increases as the time since the last ophthalmologic examination lengthens, suggesting progressive myopic regression (χ^2 statistic = 18.047, $P = 0.001$). Significant astigmatism (≤ −0.75 D) does not show a clear trend over time, with no significant association observed (χ^2 statistic = 8.907, $P = 0.167$). The prevalence of diagnosed dry eye is highest among those with a recent ophthalmologic examination and decreases over time (χ^2 statistic = 20.020, $P < 0.001$). Similarly, the prevalence of self-reported dry eye symptoms declines as the time since the last ophthalmologic examination increases (χ^2 statistic = 12.923, $P = 0.012$).

Discussion

This study offers a detailed analysis of the demographic and clinical profiles of individuals who underwent corneal refractive surgery, based on data from the KNHANES 2010–2012 dataset. Among the 595 participants, 24.2%

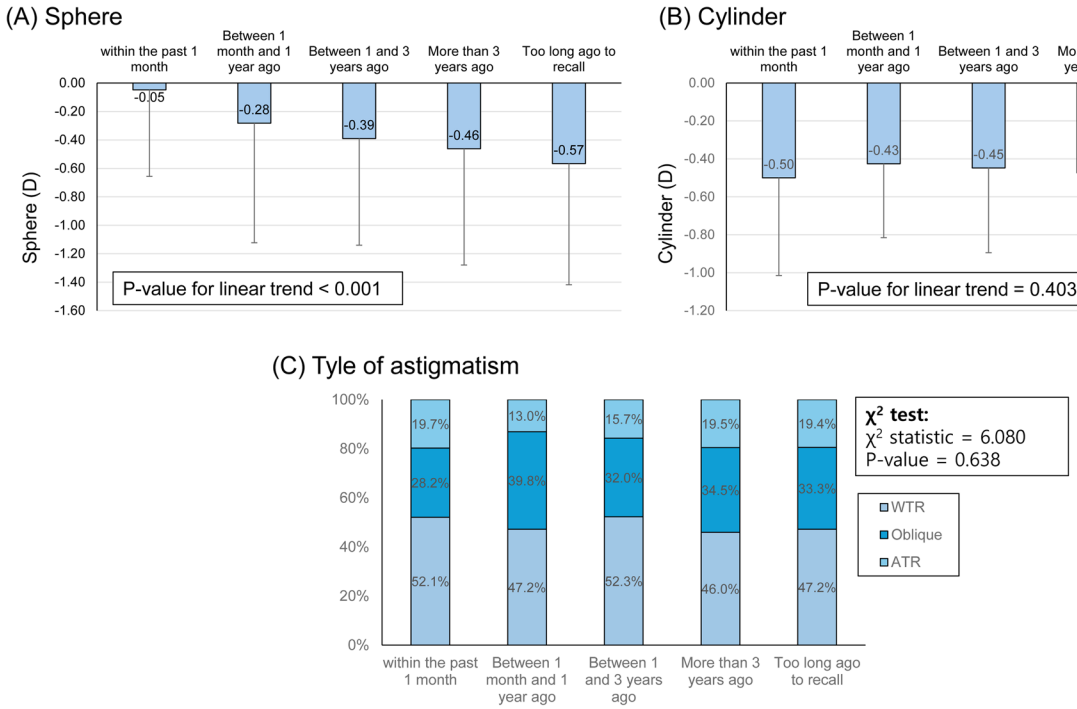

Fig. 5 Relationship between the timing of the last ophthalmologic examination and refractive error measurements, as well as astigmatism types. In this study, the timing of the last ophthalmologic examination was used as a proxy to estimate the time since surgery. **A** Sphere: Mean spherical refractive error across different time groups. **B** Cylinder: Mean cylindrical refractive error across different time groups. **C** Astigmatism Types: Distribution of with-the-rule (WTR), against-the-rule (ATR), and oblique astigmatism across different time groups

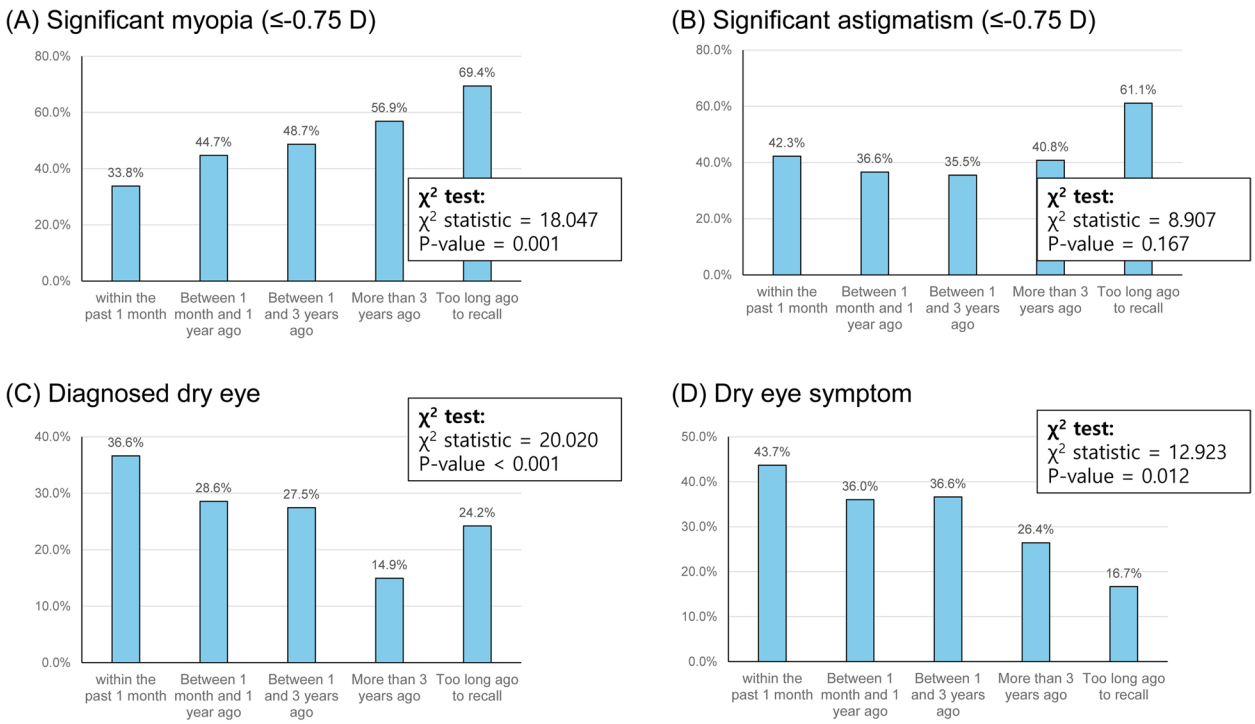

Fig. 6 Relationship between the timing of the last ophthalmologic examination and key postoperative outcomes, including refractive errors and dry eye disease. The timing of the last ophthalmologic examination was used as a proxy to estimate the time since surgery. **A** Significant myopia (≤ −0.75 D): The proportion of participants with significant myopia increases with longer time since the last ophthalmologic examination (χ^2 statistic = 18.047, $P = 0.001$). **B** Significant astigmatism (≤ −0.75 D): No significant association was observed (χ^2 statistic = 8.907, $P = 0.167$). **C** The prevalence of diagnosed dry eye is highest among those with a recent ophthalmologic examination and decreases over time (χ^2 statistic = 20.020, $P < 0.001$). **D** The prevalence of dry eye symptoms decreases with longer time since the last ophthalmologic examination (χ^2 statistic = 12.923, $P = 0.012$)

reported a diagnosis of dry eye disease, while 33.1% reported experiencing dry eye symptoms. These rates are significantly higher compared to the overall population surveyed using the same dataset, where the prevalence of diagnosed dry eye disease was 8.0% and dry eye symptoms were reported by 14.4% [9]. Persistent refractive errors, including significant myopia and astigmatism, were observed in 49.4% and 39.7% of the participants, respectively. The study also identified significant factors associated with dry eye disease and symptoms, such as female sex, prolonged sun exposure. Importantly, no significant association was found between refractive surgery and specific ocular diseases, apart from dry eye disease and myopic regression. These findings provide valuable epidemiological insights into the complications and outcomes of corneal refractive surgery within a nationally representative population. Considering the period of data collection, most surgeries reported by participants likely involved LASIK and PRK, positioning this study as the first to present statistical data on these procedures within this population. Previous research on laser vision correction has predominantly focused on LASIK and PRK [16]. However, as many surgeons are involved in research and results are often published by the institutions where the surgeries were performed, there is potential for statistical bias. While this study does not distinguish between specific types of corneal refractive surgeries, it provides an objective, unbiased, and comprehensive overview of the broader surgical population, serving as a valuable baseline for evaluating the outcomes.

The absence of preoperative ocular parameters in the KNHANES limits the ability to determine whether postoperative refractive errors, such as myopic regression or astigmatism, were due to surgical technique, pre-existing conditions, or natural refractive changes over time. Additionally, while dry eye disease is a known complication of refractive surgery, we cannot distinguish between pre-existing dry eye and new-onset postoperative cases. Despite these limitations, the current study provides a population-level overview of refractive surgery outcomes and identifies key risk factors that may contribute to long-term complications. The KNHANES dataset does not include specific diagnostic data on corneal ectasia. Given that corneal ectasia is a well-recognized but rare

complication of refractive regression, its absence from our dataset represents a limitation [17]. Future studies should incorporate longitudinal data with preoperative assessments, including corneal topography, pachymetry, and tear film evaluations, to better elucidate the causal relationship between surgery and postoperative complications.

As refractive surgery techniques continue to advance, the data collected during the 2010–2012 study period may not fully reflect the current outcomes and standard practices of modern refractive procedures. A significant limitation of this study is the lack of information on the specific types of surgeries performed; however, it is likely that most patients underwent LASIK or PRK [18, 19]. This study primarily focuses on data related to LASIK and PRK, which were the most performed laser vision correction procedures during the study period, while phakic IOL implantation was still uncommon at that time in Korea. While SMILE was introduced in Korea around 2010, its adoption remained limited until after 2015 [20], gaining traction following Food and Drug Administration approval in the United States in 2016. Since then, SMILE has become more commonly performed in Korea. Non-laser vision correction procedures, such as radial keratotomy, were rarely conducted in Korea [21].

This study revealed a higher prevalence of postoperative dry eye and myopia regression compared to previous reports, likely due to its unbiased methodology. For instance, a prior study reported chronic dry eye in 5.0% of PRK patients and 0.8% of LASIK patients [16], while another study observed myopic regression in 23.6% of patients over a 5-year follow-up period [22]. Unlike earlier studies, which were confined to clinical settings or small cohorts, this analysis encompasses a nationally representative population, providing a comprehensive perspective on demographic trends, ocular conditions, and risk factors associated with corneal refractive surgery. By highlighting the prevalence of dry eye disease and refractive error regression as significant postoperative concerns, this study offers valuable insights to help clinicians better understand and manage these complications in diverse patient populations. In our study population, myopic and astigmatic regression were observed as refractive errors, with significant myopia (≤ -0.75 D) and astigmatism (≤ -0.75 D) reported in 49.4% and 39.7% of participants, respectively. These findings highlight the prevalence of residual refractive errors following corneal refractive surgery, which may compromise long-term surgical success and patient satisfaction. Myopic regression is often attributed to factors such as corneal biomechanical changes, epithelial remodeling, or insufficient initial correction [5, 23]. Astigmatic regression, on the other hand, may result from axis misalignment or wound healing processes that alter corneal curvature [24]. The lack of data on specific surgical procedures or preoperative measurements limits our ability to determine the exact causes of regression in this cohort. Nevertheless, these findings emphasize the need for long-term follow-up and tailored postoperative management to address residual refractive errors and optimize outcomes for patients undergoing refractive surgery.

Corneal refractive surgeries are associated with several well-documented complications, with dry eye disease and refractive error regression being among the most frequently reported [16]. Dry eye symptoms commonly develop due to disruption of the corneal nerves during surgery, leading to tear film instability and ocular surface discomfort [25]. In this study, the prevalence of dry eye among patients who underwent refractive surgery was significantly higher than that observed in the general population, with diagnosed dry eye disease at 8.0% and dry eye symptoms reported by 14.4% in the broader population [9]. Refractive error regression, particularly in myopia and astigmatism, remains a major challenge as it can compromise long-term surgical success and patient satisfaction [26]. In contrast to these common complications, this study observed a very low prevalence of cataract (with a surgery rate of 0.3% and a diagnosis rate of 3.2% based on examination), surgically treated retinal diseases (0.2%) and glaucoma (0.5%), suggesting that these conditions are rare in the general population undergoing refractive surgery. However, it is important to note that this study does not establish a direct causal link between refractive surgery and these conditions. The cataract rate observed in this study is notably lower than the disease prevalence rate (23.5%) reported in the general population using the same KNHANES data, even after accounting for differences in population age distribution [27]. Regarding glaucoma, while a previous study suggested that refractive surgery may be a risk factor, no significant difference in glaucoma prevalence was observed between the refractive surgery and control groups in that study [8]. However, the control group in the previous study consisted only of individuals with very mild myopia (spherical equivalent (SE) < -3.00 D), which likely led to an inaccurate conclusion. In contrast, the findings of this study confirm that neither cataracts nor glaucoma are significantly associated with corneal refractive surgery. However, it is important to note that the relationship between refractive surgery and retinal disease remains inconclusive in this study, as no direct link was established. Furthermore, the prevalence of cataracts, glaucoma, and retinal diseases does not appear to be associated with refractive surgery in this population. In conclusion, while dry eye and refractive

error regression remain prominent postoperative concerns, the rarity of surgically treated retinal diseases and other severe complications shows the overall safety of corneal refractive surgery. These findings emphasize the need for clinicians to focus on managing common complications while acknowledging the low likelihood of severe adverse outcomes in patients undergoing refractive procedures.

Several studies have documented the prevalence of dry eye disease, refractive regression, and rare complications following corneal refractive surgery. Dry eye disease remains one of the most common postoperative complications, with reported prevalence rates ranging from 36 to 75% in LASIK patients [28]. Refractive error regression, particularly myopic regression, has also been observed in 15% to 50% of patients over a five-year period, depending on factors such as preoperative refraction and age [7]. A large-scale retrospective study in the Philippines found that 13% of patients developed symptomatic dry eye and 1.8% experienced significant refractive regression after LASIK or PRK [29]. Regarding rare complications, a review found that rhegmatogenous retinal detachment (RRD) occurs in approximately 0.03% to 0.19% of LASIK patients [30]. The incidence of RRD after PRK is similar, with reports indicating rates between 0.08% and 0.15%, particularly in high myopes. Cataract formation after refractive surgery is rare, but evidence suggests that repeated excimer laser ablation may contribute to cataractogenesis [31]. However, large-scale epidemiological studies indicate that the overall incidence of post-refractive-surgery cataract remains extremely low, particularly in the absence of additional risk factors [7]. Glaucoma following refractive surgery is rare; however, steroid-induced ocular hypertension can occur as a transient postoperative complication, particularly after PRK and phakic IOL implantation. A large-scale study reported an incidence of 5.58% for steroid-induced ocular hypertension among patients undergoing myopic refractive surgery, with higher rates following PRK (7.63%) compared to LASIK (0.06%). Although most cases are successfully managed by discontinuing steroids or using antiglaucoma medications, a small percentage of patients (0.02%) may develop uncontrolled intraocular pressure, requiring surgical intervention [32]. These findings are consistent with our study's observation that severe complications such as cataracts (0.3%), glaucoma (0.5%), and surgically treated retinal disorders (0.2%) were rare. Corneal ectasia is one of the most severe complications following corneal refractive surgery, though it remains rare. A large-scale retrospective study reported an incidence of 0.033% over an 8-year period following LASIK. However, in our study, the lack of objective corneal topography or tomography data prevented a comprehensive assessment of ectasia risk factors.

Our study demonstrated that dry eye was significantly associated with female sex and sun exposure following corneal refractive surgery. These findings align with existing literature and highlight the need to explore the underlying mechanisms behind these associations [33]. The higher prevalence of dry eye in females is often attributed to hormonal differences. Androgen deficiency, particularly in postmenopausal women, has been shown to impair the secretion of key components of the tear film, increasing the risk of developing dry eye [34, 35]. Additionally, fluctuations in estrogen levels may also influence tear production and ocular surface stability, further contributing to the condition. Prolonged sun exposure is a well-recognized environmental risk factor for dry eye [36]. Ultraviolet radiation (UV) can directly damage the ocular surface, disrupt the tear film, and trigger inflammatory processes that exacerbate dry eye symptoms [37]. Furthermore, outdoor exposure is often accompanied by wind and low-humidity conditions, which can accelerate tear film evaporation, compounding the risk. These findings suggest that both hormonal and environmental factors should be considered when counseling patients undergoing corneal refractive surgery. Incorporating preventive measures, such as education on UV protection, including wearing sunglasses and using artificial tears, and tailoring postoperative care for at-risk populations, particularly females, may help mitigate dry eye symptoms. By integrating these factors into the surgical planning and postoperative care process, clinicians can better manage and reduce the burden of dry eye after refractive surgery. Notably, our study also found that dry eye symptoms gradually decreased over time after surgery. This information should be communicated to patients preoperatively to provide reassurance and manage expectations regarding postoperative symptom resolution.

Despite its strengths, this study has several notable limitations. First, the type of refractive surgery performed (e.g., LASIK, PRK, or others) and the time elapsed since surgery were not recorded [38]. This lack of specificity makes it challenging to attribute outcomes such as dry eye or myopia regression to procedures or recovery stages. Given that the severity of dry eye and the degree of myopia regression differ between these surgeries, the inability to distinguish between them is a significant limitation of this study. Second, the cross-sectional design of the study precludes establishing causal relationships between risk factors and outcomes. For instance, it is unclear whether dry eye was present before surgery or if it developed because of the procedure. As this is a cross-sectional study, it cannot establish causal relationships

between refractive surgery and postoperative outcomes. The observed associations may be influenced by unmeasured confounding factors, such as preoperative ocular conditions, surgical techniques, or postoperative care. Furthermore, the absence of information on preoperative factors such as the degree of myopia or corneal thickness makes it impossible to determine the causal relationship between these factors and postoperative outcomes. Third, the KNHANES dataset relies on self-reported data for surgical history and dry eye symptoms, which may introduce recall bias. To mitigate this, participants were explicitly asked whether they had ever been diagnosed with dry eye by a physician and whether they had experienced dry eye symptoms such as irritation or dryness. The phrasing of the survey questions used to assess dry eye disease and symptoms may have influenced participant responses. Since dry eye symptoms can fluctuate or resolve over time, self-reported responses may not fully capture chronic or persistent cases. While standardized scoring systems such as the Ocular Surface Disease Index (OSDI) or Schirmer's test were not available in the dataset, the structured nature of the survey questions helps distinguish between physician-diagnosed dry eye and self-reported symptoms, similar to methodologies used in previous epidemiological studies [39]. Finally, the KNHANES dataset lacks detailed clinical information, such as corneal topography or surgical records, which would have provided valuable insights into the specific surgical techniques used and their associated outcomes. This absence of detailed data limits the study's ability to explore procedural variations and their impact on complications or recovery.

Conclusion

This study provides a detailed analysis of the demographic and clinical characteristics of individuals undergoing corneal refractive surgery, highlighting the significant prevalence of dry eye disease (24.2%) and symptoms (33.1%) as well as persistent refractive errors, including significant myopia (49.4%) and astigmatism (39.7%). Female sex and prolonged sun exposure were identified as important risk factors for dry eye, offering insights to improve preoperative and postoperative care strategies. Surgeons should also counsel patients about the possibility of myopic regression and its implications for long-term outcomes. The study confirms the low prevalence of severe conditions such as cataract (0.3%), surgically treated retinal diseases (0.2%) and glaucoma (0.5%). However, limitations such as the lack of specific surgical details, reliance on self-reported data, and the cross-sectional nature of the analysis should be addressed in future longitudinal research. Despite these limitations, this nationally representative study provides a valuable foundation for understanding the outcomes and complications associated with corneal refractive surgery and supports the development of strategies to enhance patient care. Future studies with longitudinal follow-up and comprehensive preoperative assessments are needed to further explore potential risk factors.

Abbreviations

CI	Confidence Interval
IOL	Intraocular Lens
IRB	Institutional Review Board
KNHANES	Korean National Health and Nutrition Examination Survey
LASIK	Laser-Assisted In Situ Keratomileusis
LOCS III	Lens Opacities Classification System III
OR	Odds Ratio
PRK	Photorefractive Keratectomy
SD	Standard Deviation
SMILE	Small Incision Lenticule Extraction
UV	Ultraviolet Radiation

Acknowledgements
None.

Clinical trial number
Not applicable.

Authors' contributions
Joon Yul Choi: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis. Sun Young Ryu: Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis. Tae Keun Yoo: Conceptualization, Project administration, Resources, Supervision, Writing – review & editing.

Funding
None.

Data availability
The dataset is publicly available for research at https://knhanes.kdca.go.kr/knhanes/eng/main.do.

Declarations

Ethics approval and consent to participate
This study was conducted using anonymized data from the publicly available KNHANES dataset, which was approved by the Institutional Review Board (IRB) of the Korea Centers for Disease Control and Prevention (IRB numbers: 2010-02CON-21-C, 2011–02-CON-06-C, and 2012–01-EXP-01-2C). Written informed consent was obtained from all participants prior to their inclusion in the survey. As the study exclusively utilized publicly available data, additional IRB approval was not required. The study complied with the principles outlined in the Declaration of Helsinki, ensuring ethical standards were maintained throughout.

Consent for publication
Not applicable, as this study does not include identifiable individual data, images, or personal information requiring consent for publication.

Competing interests
The authors declare no competing interests.

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Received: 25 January 2025 Accepted: 17 March 2025
Published online: 28 March 2025

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