Research Article

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Comparative Effectiveness and Safety of Modern Corneal Refractive Surgery Techniques: SMILE versus LASIK versus PRK

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ABSTRACT

Purpose: To systematically evaluate and compare the effectiveness and safety of small incision lenticule extraction (SMILE), laser in situ keratomileusis (LASIK), and photorefractive keratectomy (PRK) for myopic correction through thorough synthesis of contemporary evidence.

Methods: Systematic review was conducted following PRISMA guidelines. Comprehensive scarches were performed in PubMed/MEDLINE, Embase, Cochrane Library, Web of Science and Scopus from January 2020 to December 2025. Eligible studies included randomized controlled trials, prospective comparative studies, retrospective comparative studies, and meta- analysis comparing at least two of the three techniques for myopic correction with minimum 6-month follow-up. Primary outcomes included uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), refractive predictability (+0.50 D and +1.OO D), efficacy index and safety index. Secondary outcomes encompassed intraoperative and postoperative complications, corneal ectasia, contrast sensitivity, higher-order aberrations (coma, spherical aberration, total HOAs), and dry eye parameters (tear break-up time, Schirmer test, Ocular Surface Disease Index).

Results: From 1,034 initially identified records, 230 unique studies underwent full-text review, with 30 studies meeting inclusion criteria for qualitative synthesis. AII techniques achieved excellent visual outcomes with efficacy indices 0.94 and comparable postoperative UDVA and CDVA SMILE produced significantly larger effective optical zones (22.18 + 2.61 mm) compared to LASIK (19.54 + 1.44 mm) and PRK (19.39 + 1.66 mm), correlating with reduced spherical aberration induction. Post-refractive ectasia incidence without identifiable preoperative risk factors was lowest for SMILE (11 per 100.000 eyes), followed by PRK (20 per 100.000), and highest for LASIK (90 per 100.000), with LASIK demonstrating 4.5-fold higher risk than PRK Dry eye symptoms were most pronounced following LASIK due to extensive corneal nerve disruption, while SMILE showed superior preservation of corneal biomechanical integrity.

Conclusions: SMILE, LASIK, and PRK achieve comparable refraction results for myopic correction with efficacy indices exceeding 0.94 across all modalities However SMILE offers distinct advantages including larger effective optical zones, reduced higher-order aberration induction, lower ectasia risk and better preservation of corneal biomechanics and tear film stability: LASIK remains associated with higher ectasia rates and more pronounced dry eye symptoms PRK demonstrates intermediate safety profiles with prolonged visual recovery. Technique selection should be individualized based on preoperative corneal parameters, refraction error magnitude, patient occupation, and risk tolerance for specific complications.

Keywords: Small incision lenticule extraction; SMILE; Laser in situ keratomileusis; LASIK; Photorefractive keratectomy; PRK; Refractive surgery; Myopia; Higher-order aberrations; Corneal ectasia

Introduction

Background

Corneal refractive surgery has undergone remarkable evolution over the past three decades transforming from surface ablation techniques to sophisticated minimally invasive procedures Photorefractive keratectomy (PRK), introduced in the late 1980s, represented the first laser-based approach for myopic correction through direct photoablation of the anterior corneal stroma [1]. Despite excellent long-term stability and safety, PRK ‘s clinical adoption was initially limited by prolonged epithelial healing significant postoperative discomfort, and delayed visual recovery [2]. The development of laser in situ keratomileusis (LASIK) in the 1990s revolutionized refractive surgery by

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combining the precision of excimer laser ablation with the rapid visual recovery afforded by protective corneal flap. The subsequent introduction of femtosecond laser technology for flap creation (FS- LASIK) further enhanced safety and predictability by eliminating mechanical microkeratome-related complications [3]. LASIK rapidly became the most widely performed collective surgical procedure worldwide, with millions of procedures conducted annually: However; concerns regarding flap-related complications, biomechanical weakening, dry eye syndrome, and post-LASIK ectasia have prompted continued innovation in refractive surgery techniques [4]. Small incision lenticule extraction (SMILE), introduced clinically in 2011, represents paradigm shift in refractive surgery by eliminating both the excimer laser and the corneal flap. This femtosecond laser-based procedure creates an intrastromal lenticule corresponding to the refractive correction, which is subsequently extracted through a small 2-4 mm incision [5]. The flapless nature of SMILE theoretically preserves anterior corneal biomechanical integrity, minimizes corneal nerve disruption and reduces dry eye symptoms while maintaining the rapid visual recovery characteristic of LASIK [6]. Since its introduction, SMILE has gained widespread adoption, with over 5 million procedures performed globally as of 2025.

Rationale

Despite the proliferation of comparative studies evaluating SMILE, LASIK, and PRK significant heterogeneity exists in research designs, outcome measures, follow-up durations, and patient populations. Previous systematic reviews have typically focused on pairwise comparisons between two techniques or have been limited by inclusion of older LASIK technologies (mechanical microkeratome-based procedures) that don't reflect contemporary practice. What's more, recent advances in understanding corneal biomechanics, higher-order aberrations and long-t term ectasia risk have generated new evidence that warrants thorough synthesis. The clinical decision-making process for selecting the optimal refractive surgery technique requires integration of multiple factors including visual outcomes, refractive predictability, Optical quality, complication rates, biomechanical stability, and patient-specific considerations such as occupation, lifestyle, and corneal parameters. A comprehensive systematic review comparing all three major contemporary techniques using standardized outcome measures is essential to inform evidence-based clinical practice and guide patient counseling.

Objectives

The primary objective of this systematic review was to comprehensively evaluate and compare the effectiveness and safety of SMILE, FS-LASIK, and PRK for myopic correction.

Specific aims included

1. To compare primary visual and refractive outcomes including UDVA , CDVA, refractive predictability (percentage of eyes within +0.50 D and +1.0O D of target refraction), efficacy index, and safety index across the three techniques.
2. To evaluate differences in higher-order aberrations (coma, spherical aberration, trefoil, total HOAs), effective optical zone dimensions, and contrast sensitivity following each procedure.
3. To assess the incidence and nature of intraoperative and postoperative complications, including dry eye parameters (tear break-up time, Schirmer test, Ocular Surface Disease Index), corneal ectasia, biomechanical changes, and other safety outcomes.

To identify patient and procedural factors that may influence comparative outcomes and inform individualized treatment selection.

Methods

Protocol Registration

This systematic review was conducted consistent with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Eligibility Criteria

Studies were included if they met the following criteria:

Population: Adult subjects (18 years) undergoing corneal refractive surgery for myopia or myopic astigmatism, with or without preoperative risk factors for ectasia.

Intervention: Small incision lenticule extraction (SMILE) using femtosecond laser technology.

Comparators: Laser in situ keratomileusis (LASIK, including femtosecond laser-assisted LASIK) and/or photorefractive keratectomy (PRK, including transepithelial PRK and sur face ablation variants).

Outcomes: Studies reporting at least one primary outcome measure (UDVA CDVA, refractive predictability, efficacy index or safety index) secondary outcome measure (complications, higher- order aberrations, contrast sensitivity, dry eye parameters, corneal ectasia, or biomechanical changes).

Study Design: Randomized controlled trials (RCTs), prospective comparative studies, retrospective comparative studies, and meta-analyses comparing at least two of the three techniques.

Follow-up Duration: Minimum follow-up of months to ensure adequate assessment of refractive stability and complication development.

Publication Period: Studies published between January 2020, and December 31, 2025 to reflect contemporary techniques and technologies.

Language: No language restrictions were applied; non-English articles were translated when necessary:

Exclusion Criteria: Case reports; case series without comparison groups, studies involving combined procedures (e.g,, SMILE with simultaneous cross-linking) , studies focusing exclusively on hyperopic or presbyopic corrections, studies with inadequate outcome reporting; and duplicate publications.

Information Sources and Search Strategy

Comprehensive electronic searches were conducted in five major bibliographic databases: PubMed/MEDLINE Embase, Cochrane Library (Cochrane Central Register of Controlled Trials), Web of Science, and Scopus. The search strategy was developed in consultation with medical librarian and incorporated both controlled vocabulary terms (Medical Subject Headings for PubMed, Entree terms for Embase) and free-text keywords to maximize sensitivity while maintaining specificity:

Study Selection

All retrieved records were imported into reference management software, and duplicate entries were removed using automated

deduplication algorithms supplemented by manual verification: The research selection process was documented using PRISMA flow diagram to ensure transparency and reproducibility.

Data Extraction

A standardized data extraction form was developed and pilot-tested on five randomly selected studies to ensure consistency and completeness.

Extracted Data Elements Included

Study Characteristics: First author, publication year, country, study design, sample size (number of eyes and subjects per technique), inclusion and exclusion criteria, follow-up duration and funding sources.

Patient Demographics: Age, preoperative spherical equivalent, cylinder, corneal thickness, corneal curvature, and any reported risk factors for ectasia.

Intervention Details: Specific laser platforms used (manufacturer and model), optical zone diameter, transition zone characteristics, cap thickness (for SMILE), flap thickness and diameter (for LASIK), and any protocol variations.

Primary Outcomes: Postoperative UDVA (log MAR), postoperative CDVA (log MAR) percentage of eyes within +0.50 D of target refraction, percentage of eyes within +1.OO D of target refraction, efficacy index (ratio of postoperative UDVA to preoperative CDVA), and safety index (ratio of postoperative CDVA to preoperative CDVA).

Secondary Outcomes: Higher-order aberrations (coma, spherical aberration; trefoil, total HOAs measured in micrometers for 6 mm pupil diameter), effective optical zone dimensions, contrast sensitivity (photopic and mesopic conditions), tear break-up time (seconds), Schirmer test results (mm/5 minutes), Ocular Surface Discase Index scores, incidence of corneal ectasia, intraoperative complications, postoperative complications (infection, haze, epithelial ingrowth, flap complications) , regression rates, and biomechanical parameters when reported.

When studies reported outcomes at multiple time points, data from the longest follow-up period were extracted for primary analysis, with intermediate time points recorded for sensitivity analysis.

Quality Assessment

For randomized controlled trials, the Cochrane Risk of Bias 2.0 (RoB 2.0) tool was employed, evaluating five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. Each domain was rated as low risk, some concerns, or high risk of bias, with an overall risk of bias judgment derived according to the RoB 2.0 algorithm: For observational comparative studies (prospective and retrospective cohort studies), the Newcastle-Ottawa Scale (NOS) was utilized. This tool assesses three domains: selection of study groups (4 points), comparability of groups (2 points), and ascertainment of outcomes (3 points), with a maximum score of 9 points. Studies scoring 7-9 points were considered high quality, 4-6 points moderate quality, and 0-3 points low quality: For meta- analyses and systematic reviews, the AMSTAR 2 (A Measurement Tool to Assess systematic Reviews) was applied to evaluate methodological quality across 16 domains, with particular attention to critical domains including protocol registration, comprehensive search strategy, duplicate study selection and data extraction, risk of bias assessment, and appropriate statistical methods.

Quality assessment results were used to inform interpretation of findings and sensitivity analyses, but no studies were excluded based solely on quality scores.

Statistical Analysis

Due to substantial heterogeneity in outcome reporting measurement methods follow-up durations, and patient populations across included studies, formal meta-analysis with pooled effect estimates wasn't feasible for all outcomes. Where sufficient homogeneity existed (at least three studies reporting the same outcome using comparable methods and time points), random- effects meta- analysis was planned using the Der Simonian-Laird method to account for between- study variability: For continuous outcomes (UDVA CDVA HOAs, dry eye parameters) weighted mean differences or standardized mean differences with 95% confidence intervals were calculated. For dichotomous outcomes (percentage within target refraction, complication rates), risk ratios O odds ratios with 95% confidence intervals were computed. Statistical heterogeneity was quantified using the 12 statistic, with values of 25%, 50%, and 75% representing low, moderate and high heterogeneity, respectively: When meta-analysis wasn't appropriate due to heterogeneity or insufficient data, narrative synthesis was employed, organizing findings by outcome category and technique comparison. Subgroup analyses were planned based on degree of myopia (low: <-3.00 D; moderate:-3.00 to-6.00 D; high: >-6.00 D), follow-up duration (6-12 months, 1-3 years; >3 years), and study design (RCTs versus observational studies) when adequate data were available. Publication bias assessment through funnel plot examination and Egger's test was planned for outcomes with at least 10 included studies. All statistical analyses were conducted using R software (version 4.3.0) with the meta and metaphor packages.

Results

Study Selection and Characteristics

The comprehensive database searches identified 1,034 records across PubMed/MEDLINE (n- 294), Embase (n-186), Cochrane Library (n-142), Web of Science (n-218), and Scopus (n=194). After removal of 804 duplicate records, 230 unique citations underwent title and abstract screening: Following this initial screening, 87 studies were excluded based on irrelevant population (n-23), Wrong intervention or comparator (n-31), inadequate outcome reporting (n-18), or inappropriate study design (n-15). The remaining 143 studies proceeded to full-text review: Full-text assessment resulted in exclusion of 113 studies for the following reasons: insufficient follow-up duration <6 months (n-28), no direct comparison between techniques (n-34) , duplicate publication or overlapping cohorts (n=12), combined procedures (n-15), focus on hyperopia or presbyopia (n-9), inadequate methodological quality precluding data extraction (n=11), and full text unavailable despite contact with authors (n-4). Ultimately, 30 studies met all inclusion criteria

and were included in the qualitative synthesis. The 30 included studies comprised 3 randomized controlled trials, 14 prospective comparative studies, 10 retrospective comparative studies, and 3 meta-analyses or systematic reviews. Studies were conducted across multiple countries including the United States (n=8), China (n-5), Poland (n-2), Iran (n-2), India (n-2), and various other countries (n=11). The total number of eyes analyzed across primary studies was 8,847 with sample sizes ranging from 43 to 654 eyes per study. Follow-up durations ranged from 6 months to 5 years, with a median follow-up of 12 months. Among the included studies 18 compared all three techniques (SMILE, LASIK and PRK), 8 compared SMILE versus LASIK only, compared SMILE versus PRK only, and compared LASIK versus PRK only: The mean preoperative spherical equivalent ranged from-2.50 D to 7.25 D across studies, with most studies focusing on low to moderate myopia. Laser platforms varied, with SMILE procedures performed using the VisuMax femtosecond laser (Carl Zeiss Meditech) LASIK procedures using various femtosecond lasers (VisuMax, IntraLase, Femto LDV) combined with excimer laser platforms (MEL series, Allegretto, VISX), and PRK procedures using similar excimer laser platforms.

Quality Assessment

Quality assessment revealed generally moderate to high methodological rigor among included studies. The three randomized controlled trials demonstrated low to moderate risk of bias using the Cochrane RoB 2.0 tool. All three RCTs employed adequate randomization procedures and allocation concealment: However; blinding of participants and personnel wasn't feasible due to the nature of surgical interventions, introducing some concerns regarding performance bias. Outcome assessment was generally objective (visual acuity, refraction, aberrometry), mitigating detection bias concerns. Attrition rates were acceptable (<15%) in all RCTs, and selective outcome reporting wasn't evident: Among the 24 observational comparative studies assessed using the Newcastle-Ottawa Scale, 16 studies (67%) achieved high quality scores (7-9 points), studies (29%) demonstrated moderate quality (4-6 points), and study (4%) was rated as low quality (3 points). The primary limitations identified were inadequate control for confounding variables in some retrospective studies and lack of masked outcome assessment in several studies. However most studies employed objective outcome measures (automated refraction computerized aberrometry, standardized questionnaires), reducing the impact of assessment bias. The three included meta- analysis and systematic reviews demonstrated variable quality on AMSTAR assessment. Two reviews were rated as high quality with extensive search strategies, duplicate study selection and data extraction, appropriate risk of bias assessment, and transparent reporting: One review demonstrated moderate quality with some methodological limitations including lack of protocol registration and limited assessment of publication bias.

Primary Visual and Refractive Outcomes

All three refractive surgery techniques achieved excellent visual outcomes with high levels of efficacy and safety. A comprehensive three-way comparison conducted in Poland involving 120 subjects (20 PRK, 50 FS-LASIK 50 SMILE) with 180-day follow-up revealed that regardless of which procedure was performed, both UDVA and CDVA improved significantly postoperatively ($p<0.0S$), with postoperative UDVA and CDVA values being similar across all three techniques ($P>0.05$). The efficacy index for each procedure was no less than 0.94 indicating that postoperative uncorrected vision approached or exceeded preoperative best- corrected vision [2]. Large retrospective analysis from US military refractive surgery center compared visual outcomes after SMILE with PRK and LASIK outcomes during the first year of SMILE implementation: This study demonstrated comparable refractive predictability across techniques, with most eyes achieving target refraction within +0.50 D. The efficacy and safety indices were similarly high across all three procedures confirming that SMILE achieved visual outcomes equivalent to the established techniques of LASIK and PRK [5]. Refractive predictability, defined as the percentage of eyes achieving postoperative spherical equivalent within +0.50 D and +1.00 D of target refraction was consistently high across all three techniques.

Multiple studies reported that >85% of eyes achieved refraction within +0.50 D and >95% within +1.00 D for all three procedures, with no statistically notable differences between techniques for low to moderate myopia. A correlation and regression analysis examining 654 eyes treated with various techniques including LASIK, FS-LASIK, and PRK showed that the correlation between final spherical equivalent and postoperative UDVA was strongest for FS-LASIK (r-0.774) and LASIK (r-0.706), with slightly lower correlations for PRK (r-0.480), suggesting that final visual outcomes were more tightly coupled to residual refractive error in LASIK procedures [1]. Safety indices, calculated as the ratio of postoperative CDVA to preoperative CDVA, consistently exceeded 1.0 across all three techniques in most studies, indicating that best-corrected vision was maintained or improved following surgery: No studies reported significant loss of best-corrected vision (defined as loss of 2 lines of Snellen acuity in more than 1% to 2% of eyes for any technique, confirming the excellent safety profile of modern refractive surgery.

Higher-Order Aberrations and Optical Quality

Higher-order aberrations represent critical determinant of postoperative optical quality, particularly affecting night vision and contrast sensitivity: comprehensive retrospective analysis of 188 eyes (61 LASIK 84 PRK, 43 SMILE) with 1-year follow-up using Pentacam tangential difference maps and wavefront aberration analysis revealed notable differences in effective optical zone (EOZ) dimensions and HOA induction patterns across techniques. SMILE produced significantly larger EOZ areas (22.18 + 2.61 mm?) compared to LASIK (19.54 + 1.44 mm and PRK (19.39 + 1.66 mm), with $P < .001$. Smaller EOZ areas correlated strongly with greater spherical aberration induction across all groups (ILASIK–0.378,rPRK =-0.555,ISMILE =-0.501) and increased total HOA induction. Absolute decentration from the corneal vertex positively correlated with total HOA (rLASIK 0.396, IPRK 0.463, rSMILE 0.399), and vertical coma induction negatively correlated with vertical decentration across all groups [3]. A detailed comparative analysis of corneal higher-order aberrations after LASIK, PRK, and SMILE examined correlations with changes in myopic Q-value and spherical equivalent with and without astigmatism. This study showed that SMILE induced less spherical aberration compared to LASIK and PRK, particularly in eyes

with higher degrees of myopic correction. The preservation of larger effective optical zones in SMILE was attributed to the lenticule extraction technique, which maintains more uniform stromal architecture compared to the ablation profiles used in LASIK and PRK [6]. A matched comparison study specifically evaluating corneal higher-order aberrations induced by SMILE versus femtosecond-assisted LASIK versus PRK in correcting moderate and high myopia analyzed aberrations at both 3.00 mm and 6.00 mm optical zones. At the 6.00mm zone, which is more relevant for mesopic and scotopic conditions, SMILE showed notably lower induction of spherical aberration and total HOAs compared to both LASIK and PRK . This finding has important clinical implications for subjects with large scotopic pupils who may experience more pronounced night vision disturbances following LASIK o PRK [7]. Contrast sensitivity, another important measure of optical quality; was evaluated in several studies. comparative analysis of visual quality and optical zones after TransPRK, SMILE, and FS-LASIK for myopia correction found that while all three techniques maintained acceptable contrast sensitivity under photopic conditions, SMILE showed superior mesopic contrast sensitivity compared to LASIK and PRK, particularly at higher spatial frequencies. This advantage was attributed to the larger effective optical zones and reduced HOA induction characteristic of SMILE [8]. An analysis specifically examining differences in image quality after three laser keratorefractive procedures for myopia confirmed that SMILE subjects reported fewer visual disturbances including halos, glare, and starbursts compared to LASIK and PRK patients, particularly during nighttime driving and low-light conditions. These subjective quality of vision measures correlated with objective aberrometry findings showing reduced HOA induction following SMILE [9].

Complications and Safety Outcomes

Complication profiles differed substantially across the three techniques, reflecting their distinct surgical approaches and mechanisms of cornea modification. Dry eye syndrome represents one of the most common postoperative complaints following refractive surgery; with significant variation in incidence and severity across techniques comprehensive meta-analysis specifically examining dry eye after refractive surgery synthesized data from multiple comparative studies and found that LASIK was associated with the highest incidence and severity of postoperative dry eye symptoms, attributed to extensive disruption of corneal nerves during flap creation and stromal ablation. PRK demonstrated intermediate dry eye symptoms, primarily during the early postoperative period coinciding with epithelial healing: SMILE showed the lowest incidence of persistent dry eye symptoms, with faster recovery of tear film parameters including tear break-up time (TBUT) and Schirmer test values, reflecting preservation of corneal nerve architecture through the small incision approach [10]. Corneal ectasia represents the most serious potential complication of refractive surgery characterized by progressive corneal steepening, irregular astigmatism, and visual deterioration. Systematic review specifically examining ectasia after corneal refractive surgery synthesized data from multiple databases and identified 70 eyes with post-PRK ectasia (onset range 0.2-192 months, mcan 41 1 50 months), 1,681 eyes with post- LASIK ectasia (onset range 0.20-132 months mean 35 # 24 months), and 19 eyes with post-SMILE ectasia (onset range 1-48 months mean 18 + 13 months). Post-refractive ectasia incidences without identifiable preoperative risk factors were 20 per 100.000 eyes for PRK, 90 per 100.000 for LASIK, and 11 per 100.000 for SMILE ectasia was 4.5 times more likely after LASIK than PRK Post-LASIK ectasia was attributed to permanent disruption of corneal integrity and reduced tensile strength from both flap creation and stromal ablation: While SMILE demonstrated the lowest ectasia rate, the authors noted that SMILE's relative novelty impedes definitive long term comparison, and underestimation of surgical volume and underreporting of ectatic eyes represent important limitations [4]. Intraoperative complications varied by technique LASIK - specific complications included flap-related issues such as incomplete flaps, free caps, buttonholes, and irregular flaps, though these complications have become rare with femtosecond laser technology SMILE-specific intraoperative complications included difficult lenticule dissection, lenticule tear; and retained lenticule fragments, with incidence rates generally <2% in experienced hands. PRK had minimal intraoperative complications given its surface ablation approach though decentration and irregular ablation patterns could occur with inadequate patient fixation or eye tracking: Postoperative complications also demonstrated technique-specific patterns. LASIK was as sociated with risks of epithelial ingrowth (1% to 3% incidence), flap displacement or dislocation (particularly with trauma), and diffuse lamellar keratitis (rare with modern techniques) PRK was characterized by prolonged epithelial healing (3-5 days), significant postoperative pain during epithelial regeneration, and risk of corneal haze (particularly with higher myopic corrections, though largely mitigated by mitomycin-C application). SMILE demonstrated low rates of interface inflammation and minimal risk of traumatic complications given the absence of a flap. Regression rates, defined as myopic shift of 0.50 D from the 3-month postoperative refraction were generally low across all three techniques for low to moderate myopia. A study examining visual outcomes of early enhancement following SMILE versus LASIK found that 0.5% of eyes post-SMILE and 0.44% of eyes post-LASIK required enhancement procedures, indicating comparable refractive stability. Enhancement after SMILE was performed using PRK and demonstrated comparable results to flap lift after LASIK, confirming that enhancement is safe and effective for both techniques [11].

Corneal Biomechanics

Preservation of corneal biomechanical integrity represents critical consideration in refractive surgery as biomechanical weakening may predispose to ectasia and influence long-term refractive stability. Multiple studies have evaluated corneal biomechanical changes following SMILE, LASIK, and PRK using various assessment methods including the Ocular Response Analyzer (ORA and Corvis ST dynamic Scheimpflug analyzer: matched comparison study specifically examining corneal biomechanics after SMILE femtosecond assisted LASIK, and PRK found that SMILE preserved corneal biomechanical properties more effectively than LASIK, with PRK demonstrating intermediate biomechanical changes. Corneal hysteresis (CH) and corncal resistance factor (CRF) , two key parameters measured by the ORA, decreased significantly following all three procedures, but the magnitude of decrease was smallest for SMILE, intermediate for PRK, and largest for LASIK. These findings were attributed to SMILE's preservation of anterior corneal lamellae and

Bowman's layer which contribute disproportionately to corneal biomechanical strength [12]. An in vivo study examining corneal biomechanical response to three different laser corneal refractive surgeries using advanced Corvis ST parameters confirmed that SMILE induced less biomechanical weakening compared to LASIK and PRK. The study evaluated multiple biomechanical parameters including deformation amplitude, peak distance, and stiffness parameter at first applanation, finding that SMILE eyes demonstrated biomechanical responses more similar to unoperated eyes compared to LASIK and PRK eyes at 12-month follow-up [13]. Comprehensive study examining biomechanical effects of transepithelial PRK (tPRK), FS LASIK, and SMILE on the cornea using finitc element modeling and clinical measurements found that the flapless nature of SMILE and PRK resulted in better preservation of anterior corneal biomechanical integrity compared to LASIK. However, SMILE demonstrated advantages over PRK in preserving overall corneal biomechanical stability due to the absence of Bowman's layer removal and more uniform stromal architecture following lenticule extraction [14]. Long-term studies examining posterior corneal stability have provided additional insights into biomechanical differences. Study evaluating changes in posterior cornea and posterior to anterior curvature radii ratio 1 year after LASIK, PRK, and SMILE treatment of myopia found that all three procedures induced some degree of posterior corneal steepening, but the magnitude was smallest for SMILE, intermediate for PRK, and largest for LASIK. Posterior corneal changes are considered sensitive indicator of biomechanical weakening, and the reduced posterior corneal changes following SMILE suggest superior biomechanical preservation [15].

S-year longitudinal study examining the impact of ablation ratio on postoperative posterior corneal stability after refractive surgery compared SMILE and FS-LASIK The study found that eyes with higher ablation ratios (ratio of tissue removed to residual stromal bed thickness) demonstrated greater posterior corneal steepening over time, but this effect was significantly more pronounced in LASIK eyes compared to SMILE eyes, suggesting that SMILE provides better long-term biomechanical stability even in eyes with higher ablation ratios [16].

Discussion

Summary of Evidence

This systematic review synthesized evidence from 30 comparative studies encompassing 8,847 eyes to evaluate the effectiveness and safety of SMILE, LASIK, and PRK for myopic correction: The evidence demonstrates that all three techniques achieve excellent visual outcomes with efficacy indices 0.94 and comparable postoperative UDVA and CDVA. Refractive predictability is similarly high across techniques, with >85% of eyes achieving refraction within +0.50 D and >95% within +1.00 D of target for low to moderate myopia. Safety indices consistently exceed 1.0, indicating maintenance or improvement of best-corrected vision following surgery. However, important differences emerge when examining optical quality, complication profiles, and biomechanical outcomes. SMILE produces significantly larger effective optical zones (22.18 12.61 mm) compared to LASIK (19.54 + 1.44)mm and PRK (19.39 + 1.66 mm), correlating with reduced spherical aberration induction and superior mesopic contrast sensitivity: This optical advantage translates to fewer patient-reported visual disturbances including halos, glare and starbursts, particularly during nighttime activities. Complication profiles differ substantially across techniques. Dry eye syndrome is most pronounced following LASIK due to extensive corneal nerve disruption during flap creation and stromal ablation, with slower recovery of tear film parameters SMILE demonstrates the lowest incidence of persistent dry eye symptoms, attributed to preservation of corneal nerve architecture through the small incision approach: PRK shows intermediate dry eye symptoms, primarily during early postoperative epithelial healing: Corneal ectasia risk varies significantly across techniques. Post-refractive ectasia incidence without identifiable preoperative risk factors is lowest for SMILE (11 per 100.000 eyes) followed by PRK (20 per 100.000) and highest for LASIK (90 per 100.000), with LASIK demonstrating 4.5-fold higher risk than PRK. These differences reflect the biomechanical consequences of each surgical approach, with LASIK's combination of flap creation and stromal ablation producing the greatest biomechanical weakening: Corneal biomechanical studies consistently demonstrate superior preservation of biomechanical integrity following SMILE compared to LASIK, with PRK showing intermediate effects SMILE preserves anterior corneal lamellae and Bowman layer which contribute disproportionately to corneal biomechanical strength. Long-term studies show reduced posterior corneal steepening following SMILE compared to LASIK and PRK, suggesting better biomechanical stability over time.

Comparison with Existing Literature

The findings of this systematic review are generally consistent with previous meta-analyses and systematic reviews comparing refractive surgery techniques, while providing updated evidence incorporating recent studies and longer follow-up data. Earlier systematic reviews comparing SMILE and LASIK found comparable visual outcomes but noted SMILE's advantages in dry eye symptoms and patient comfort consistent with our findings. However previous reviews were limited by shorter follow-up durations and fewer studies directly comparing all three techniques. Our finding of larger effective optical zones following SMILE compared to LASIK and PRK extends previous observations and provides mechanistic insight into SMILE 's superior optical quality outcomes. The correlation between smaller effective optical zones and greater spherical aberration induction across all techniques highlights the importance of optical zone dimensions in determining postoperative optical quality regardless of the specific technique employed. The ectasia risk data synthesized in this review provide the most comprehensive comparison to date across all three techniques. While previous reviews have documented post- LASIK ectasia risk, the inclusion of SMILE ectasia data with longer follow-up and larger case series allows for more robust risk estimation: The 4.5-fold higher ectasia risk for LASIK compared to PRK and the even lower risk for SMILE have important implications for patient selection and informed consent discussions. Recent biomechanical studies using advanced assessment technologies (Corvis ST, finite element modeling) have provided new insights into the mechanisms underlying biomechanical differences across techniques. Our synthesis of these studies confirms that SMILE s preservation of anterior corneal architecture translates to measurable biomechanical advantages, supporting the theoretical rationale for SMILE's flapless approach. Some discrepancies exist between our findings and earlier literature

.Older studies comparing LASIK and PRK often reported superior visual recovery speed for LASIK, which remains true but did not adequately account for PRK's advantages in biomechanical preservation and lower ectasia risk: The introduction of SMILE has shifted the risk-benefit calculus, offering rapid visual recovery comparable to LASIK while maintaining biomechanical advantages similar to or exceeding PRK.

Clinical Implications

The evidence synthesized in this review has several important clinical implications for patient selection, surgical planning and informed consent: While all three techniques achieve excellent visual outcomes for low to moderate myopia; the choice of technique should be individualized based on patient-specific factors and risk profiles SMILE appears to offer the most favorable overall profile for many patients, combining rapid visual recovery, excellent optical quality with large effective optical zones, minimal dry eye symptoms, lowest ectasia risk; and superior biomechanical preservation: SMILE may be particularly advantageous for patients with occupations or lifestyles involving contact sports O risk of ocular trauma, given the absence of a flap that could be displaced. Patients with borderline corneal thickness or biomechanical parameters may also benefit from SMILE's superior biomechanical preservation: Also, patients with preexisting dry eye symptoms or risk factors for dry eye may experience better outcomes with SMILE compared to LASIK remains a highly effective option with the advantages of rapid visual recovery, minimal postoperative discomfort, and extensive long-term safety data spanning three decades LASIK may be preferred for patients requiring enhancement procedures; as flap lift provides straightforward enhancement approach: However patients should be counseled regarding higher risks of dry eye symptoms and ectasia compared to SMILE and PRK, and LASIK should be avoided in patients with significant preoperative risk factors for ectasia including thin corneas, high myopia, forme fruste keratoconus, suspicious topographic patterns PRK offers advantages of no flap-related complications, lower ectasia risk than LASIK, and suitability for patients with thin corneas or irregular corneal surfaces PRK may be the preferred option for patients with very thin corneas where SMILE or LASIK would leave insufficient residual stromal bed thickness, or for patients with anterior basement membrane dystrophy or recurrent erosion syndrome. However patients should be counseled regarding prolonged visual recovery (typically 1-2 weeks), significant postoperative discomfort during epithelial healing and risk of corneal haze with higher myopic corrections. For patients with high myopia (>-6.00 D), careful consideration of residual stromal bed thickness, ablation ratio, and ectasia risk is essential regardless of technique. SMILE may offer biomechanical advantages in this population, but long-term data remain more limited compared to LASIK and PRK. Some surgeons advocate for combined procedures (refractive surgery with simultaneous sequential collagen cross-linking) in high myopia to enhance biomechanical stability, though this approach requires further validation: Patient counseling should include detailed discussion of technique- specific advantages, disadvantages, and complication profiles Informed consent should address the trade-offs between rapid visual recovery (favoring LASIK and SMILE over PRK), optical quality (favoring SMILE), dry eye risk (favoring SMILE and PRK over LASIK), ectasia risk (favoring SMILE and PRK over LASIK) and biomechanical preservation (favoring SMILE) Shared decision making incorporating patient preferences, lifestyle factors, and risk tolerance is essential for optimal outcomes and patient satisfaction.

Limitations

Several limitations of this systematic review warrant consideration First; substantial heterogeneity existed across included studies in terms of study design, patient populations, techniques and parameters; outcome measures, and follow-up durations. This heterogeneity precluded formal meta-analysis for many outcomes, necessitating narrative synthesis. While narrative synthesis provides valuable insights, it lacks the statistical precision of quantitative meta-analysis and may be more susceptible to subjective interpretation. Next, the majority of included studies were observational comparative studies (prospective or retrospective cohort designs) rather than randomized controlled trials. While observational studies can provide valuable real-world evidence, they are more susceptible to selection bias, confounding, and other methodological limitations compared to RCTs. Only three RCTs were identified, reflecting the practical and ethical challenges of randomizing patients to different refractive surgery techniques.Residual confounding by indication (systematic differences in patient characteristics across technique groups) may have influenced some comparative findings. Finally, follow-up durations were relatively short in many studies (median 12 months), limiting asscssment of long- term outcomes including late-onset ectasia, refractive regression, and progressive biomechanical changes. Ectasia can develop years o even decades after refractive surgery, and the relatively recent introduction of SMILE (2011) means that very long-term ectasia risk data (>10 years) are not yet available. The lower ectasia rates reported for SMILE may partially reflect shorter cumulative follow-up time and smaller total surgical volumes compared to LASIK and PRK Last, outcome reporting was inconsistent across studies, with many studies reporting only subset of outcomes of interest . For instance, while most studies reported visual acuity and refraction outcomes, fewer studies reported comprehensive higher-order aberration data, dry eye parameters, or biomechanical measurements. This selective outcome reporting limited our ability to perform comprehensive comparisons across all outcomes of interest. Fifth, technique parameters varied substantially across studies, including optical zone diameters, transition zone characteristics, flap thickness, and specific laser plat forms. These technical variations may influence outcomes but could not be systematically evaluated due to insufficient reporting and heterogeneity. Surgeon experience and learning curves may also have influenced outcomes, particularly for SMILE which has steeper learning curve than LASIK or PRK. Sixth, publication bias represents a potential concern as studies with positive or statistically significant findings may be more likely to be published than studies with null o negative findings. Seventh most included studies focused on low to moderate myopia, with fewer studies examining high myopia (>-6.00 D) or myopic astigmatism: Generalizability of findings to these populations may be limited. Also, most studies excluded patients with preoperative risk factors for ectasia, limiting assessment of technique performance in higher-risk populations Finally, patient- reported outcomes including quality of life, visual

symptoms, and satisfaction were inconsistently reported across studies, limiting our ability to comprehensively evaluate these important patient-centered outcomes. Future studies should incorporate standardized patient reported outcome measures to facilitate comparison and synthesis.

Future Research Directions

Several important research gaps and future directions emerge from this systematic review: First, additional high-quality randomized controlled trials directly comparing all three techniques (SMILE, LASIK, and PRK) with standardized outcome measures and long-term follow-up (5 years) are needed to provide the highest level of evidence for comparative effectiveness. Such trials should employ rigorous methodology including adequate sample sizes, allocation concealment masked outcome assessment where feasible, and comprehensive outcome reporting including visual acuity, refraction, optical quality, complications, biomechanics, and patient- reported outcomes Next, long-term studies (10 years) examining ectasia risk, refractive stability, and biomechanical changes following SMILE are essential to definitively establish SMILE's long-term safety profile. While early and intermediate-term data are encouraging, very long-term outcomes comparable to the extensive LASIK and PRK literature are needed. Prospective registries tracking large cohorts of SMILE patients over extended follow-up periods would provide valuable real-world evidence. Finally, studies examining technique performance in specific patient subgroups are needed to refine patient selection criteria. Subgroups of particular interest include high myopia (>-6.00 D); thin corneas, large pupils, high astigmatism, and patients with borderline topographic findings. Comparative studies in these populations would inform evidence-based decision making for patients who may be at higher risk for complications or suboptimal outcomes. Last, research examining the role of advanced diagnostic technologies in preoperative screening and risk stratification is needed. Technologies including epithelial thickness mapping, corneal biomechanical assessment (Corvis ST, Brillouin microscopy), and artificial intelligence-based analysis of topographic patterns may improve identification of patients at risk for ectasia or other complications. Studies validating these technologies and establishing evidence-based screening protocols would enhance patient safety: Fifth investigation of enhancement strategies following each primary technique is important as 5% to 10% of patients may require enhancement procedures to achieve optimal refraction results. Comparative studies examining different enhancement approaches (PRK after SMILE, flap lift after LASIK, repeat PRK after PRK) would inform evidence-based enhancement protocols. Sixth research examining combined procedures, particularly refractive surgery with simultaneous or sequential collagen cross-linking, may identify approaches to enhance biomechanical stability and reduce ectasia risk in higher-risk populations. Randomized trials comparing combined procedures to standard techniques in high-risk patients would provide valuable evidence regarding the risk-benefit profile of these approaches. Seventh, studies incorporating comprehensive patient-reported outcome measures including quality of life, visual symptoms, satisfaction and return to normal activities would provide important patient- centered evidence to complement objective clinical outcomes. Development and validation of refractive surgery-specific patient-reported outcome instruments would facilitate standardized assessment across studies Eighth, cost-effectiveness analyses comparing the three techniques from both healthcare system and societal perspectives would inform resource allocation decisions and value-based care initiatives. Such analysis should incorporate not only direct surgical costs but also costs associated with complications, enhancement procedures, and quality-adjusted life years. Finally research examining the mechanisms underlying differences in optical quality, biomechanical changes, and complication rates across techniques would provide fundamental in sights to guide future technological innovations. Advanced imaging techniques, computational modeling, and basic science investigations of corneal wound healing and biomechanics may identify opportunities for further optimization of refractive surgery techniques.

Conclusions

This systematic review provides comprehensive evidence comparing the effectiveness and safety of SMILE, LASIK, and PRK for myopic correction. All three techniques achieve excellent visual outcomes with efficacy indices 0.94, comparable postoperative UDVA and CDVA, and high refractive predictability. However important differences exist in optical quality, complication profiles, and biomechanical outcomes that should inform individualized treatment selection. SMILE offers distinct advantages including significantly larger effective optical zones (22.18 + 2.61 mm) compared to LASIK (19.54 + 1.44 mm)and PRK(19.39 + 1.66 mm), correlating with reduced higher-order aberration induction and superior mesopic contrast sensitivity: SMILE demonstrates the lowest incidence of persistent dry eye symptoms due to preservation of corneal nerve architecture and the lowest ectasia risk (11 per 100.000 eyes) compared to PRK (20 per 100.000) and LASIK (90 per 100.000). Biomechanical studies consistently demonstrate superior preservation of corneal biomechanical integrity following SMILE, with reduced posterior corneal steepening and better long-term stability. LASIK remains a highly effective option with rapid visual recovery and extensive long term safety data, but is associated with higher risks of dry eye symptoms and ectasia compared to SMILE and PRK. LASIK should be avoided in patients with significant preoperative risk factors for ectasia. PRK offers advantages of no flap- related complications and lower ectasia risk than LASIK, making it suitable for patients with thin corneas or irregular corneal surfaces. However, PRK is characterized by prolonged visual recovery and significant postoperative discomfort during epithelial healing: Technique selection should be individualized based on preoperative corneal parameters, refraction error magnitude; patient occupation and lifestyle, and risk tolerance for specific complications. Comprehensive patient counseling regarding technique-specific advantages, disadvantages, and complication profiles is essential for informed decision-making and optimal outcomes. Future research should focus on long-term randomized controlled trials with standardized outcome measures, studies in specific patient subgroups, validation of advanced diagnostic technologies for risk stratification and comprehensive patient-reported outcome assessment to further refine evidence-based practice in refractive surgery:

Conflicts of Interest
The author declare no conflicts of interest

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Data Availability
All data supporting the findings of this systematic review are available within the article and its references.

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