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Artificial Intelligence in Corneal Refractive Surgery: A Bibliometric Analysis of Research Hotspots, Development Trends, and Emerging Directions

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Systematic Review

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Artificial Intelligence in Corneal Refractive Surgery: A Bibliometric Analysis of Research Hotspots, Development Trends, and Emerging Directions

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Abstract

Purpose

To characterize the research landscape, major hotspots, and evolving trends in artificial intelligence (AI) applications in corneal refractive surgery and to examine how these applications differ across surgical procedures.

Methods

English-language Articles and Reviews published between January 2018 and July 12, 2026 were identified from the Web of Science Core Collection (WoSCC). VOSviewer and CiteSpace were used to examine publication trends, countries, institutions, authors, keywords, thematic clusters, temporal patterns, and citation bursts. AI applications were then compared across SMILE, LASIK/FS-LASIK, and PRK/TransPRK.

Results

The analysis included 79 publications. Publication activity increased after 2022 and reached its highest level in 2026. China and the United States were prominent contributors and occupied central positions in the international collaboration network. Major research themes included artificial intelligence, deep learning, machine learning, LASIK, SMILE, corneal imaging, and keratoconus. Over time, the research focus moved from refractive surgery safety assessment toward AI-assisted analysis and imaging applications. Across LASIK, SMILE, and PRK, AI research mainly addressed corneal parameter assessment, surgical evaluation, and prediction of postoperative outcomes.

Conclusions

AI research in corneal refractive surgery has expanded considerably in recent years, with increasing emphasis on deep learning, machine learning, and corneal imaging. Current studies mainly concern LASIK, SMILE, and PRK, covering preoperative assessment, corneal parameter analysis, and postoperative outcome prediction. The present bibliometric analysis maps the main research directions and their development over time and may help identify areas for further investigation and clinical translation.

Keywords:

Artificial intelligence; Corneal refractive surgery; Bibliometric analysis; Machine learning; LASIK; SMILE

1. Introduction

In recent years, artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL), has advanced rapidly in medicine and has been increasingly applied to disease diagnosis, medical image analysis, risk prediction, and clinical decision support.[1, 2]Ophthalmology has become an active area of AI research,

supported by the large volume and relatively standardized nature of ophthalmic imaging data.[3]

Corneal refractive surgery is an important approach for correcting refractive errors and includes LASIK, FS-LASIK, PRK, TransPRK, and SMILE. AI has been increasingly used in this field for keratoconus screening, corneal ectasia risk assessment, corneal image analysis, postoperative outcome prediction, and surgical planning, providing new opportunities for more precise and personalized treatment.[1, 3]

Despite these developments, bibliometric studies examining the research landscape, knowledge structure, and evolving hotspots of AI in corneal refractive surgery remain limited, particularly studies that compare different surgical procedures. This study therefore used the Web of Science Core Collection database and bibliometric methods to examine the development, research hotspots, and evolving trends of AI applications in corneal refractive surgery, with a further comparison across surgical procedures. The findings may provide a reference for future research and clinical practice.[4]

2. Materials and Methods

2.1 Data Source

The Web of Science Core Collection (WoSCC) database served as the data source for this study. It provides citation-indexed literature with comprehensive citation information and standardized bibliographic records and is widely used for bibliometric research in medicine and knowledge mapping.[5]

2.2 Search Strategy

A Topic Search (TS) was conducted in the Web of Science Core Collection (WoSCC), covering titles, abstracts, author keywords, and Keywords Plus. The search was completed on July 12, 2026, and covered publications from January 1, 2018, to July

12, 2026. The search was limited to English-language Articles and Reviews. All retrieved records were exported as Plain Text files in the "Full Record and Cited References" format (Table 1).

Table 1 Search strategy for retrieving relevant literature from the Web of Science Core Collection

Order	Search terms
#1	TS=("artificial intelligence"OR"machine learning"OR"deep learning"OR"neural network"OR"convolutional neural network")
#2	TS=("corneal refractive surgery"OR "keratorefractive surgery"OR LASIK OR "laser-assisted in situ keratomileusis"OR"femtosecond LASIK" OR SMILE OR"small incision lenticule extraction" OR PRK OR"photorefractive keratectomy" OR TransPRK OR"transepithelial photorefractive keratectomy")
#3	TS=(cornea OR corneal OR ophthalmology OR ophthalmic OR eye OR ocular)
#4	#1 AND #2 AND #3
Database	Web of Science Core Collection
Time span	January 1,2018-July 12,2026
Document types	Article and Review Article
Language	English
Search field	Topic(TS)

2.3 Inclusion and Exclusion Criteria

Eligible publications met the following criteria: (1) addressed the application of artificial intelligence in corneal refractive surgery; (2) involved LASIK, FS-LASIK, SMILE, PRK, TransPRK, or related preoperative assessment, risk prediction, or treatment outcome evaluation; (3) were classified as Articles or Reviews; (4) were published in English; and (5) were indexed in the WoSCC. Publications unrelated to the study topic, duplicates, non-research publications (e.g., Editorials, Letters, and Meeting Abstracts), and records with incomplete bibliographic information were excluded. A total of 79 publications were ultimately included.

2.4 Data Extraction and Preprocessing

The retrieved records were exported as Plain Text files in the "Full Record and Cited

References” format. The included publications were manually reviewed, and author, institutional, and keyword information was standardized to minimize the influence of naming variations on the analysis. The processed data were then imported into VOSviewer[6]and CiteSpace[7]for visualization and bibliometric analysis.

2.5 Bibliometric Analysis

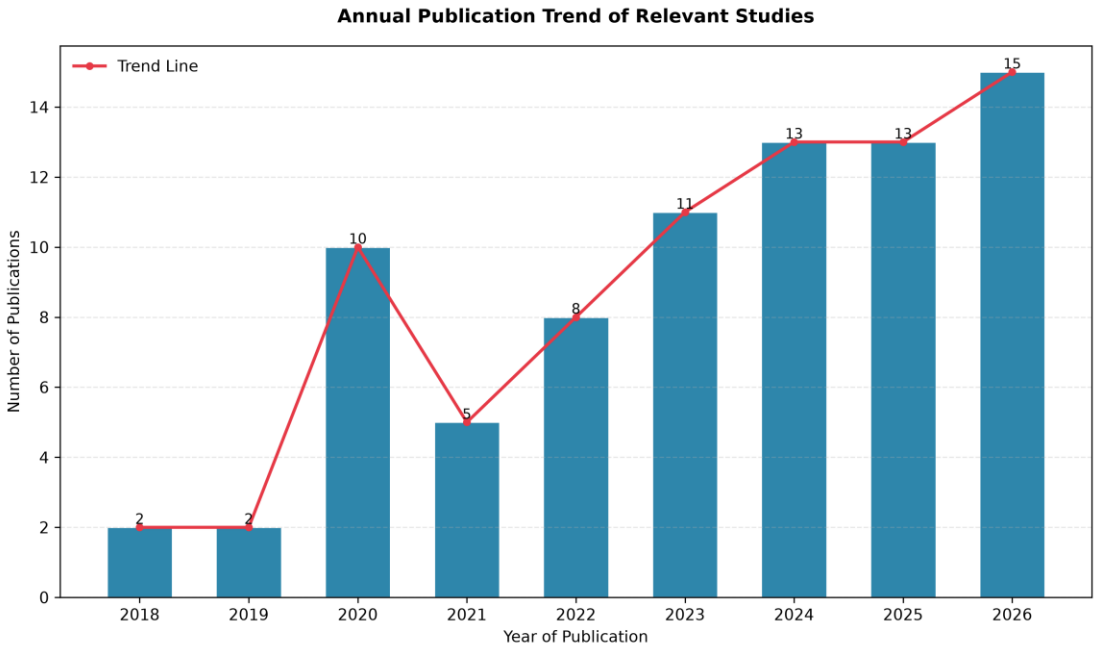
Bibliometric analyses were conducted using VOSviewer (Version 1.6.21) and CiteSpace (Version 7.0.0). VOSviewer was used to construct collaboration networks of countries, institutions, and authors, as well as keyword co-occurrence networks. Association Strength was used to calculate the strength of network relationships.[6]Node size represented publication output, while links represented collaboration or co-occurrence relationships; link width indicated the strength of these relationships. CiteSpace was used for keyword clustering, timeline analysis, and burst detection to characterize research hotspots, knowledge structures, and their evolution over time.[7]

3. Results

3.1 Included Publications and Annual Publication Trends

A total of 79 publications were included between 2018 and 2026. Annual output increased over the study period (Fig. 1), from 2 publications in both 2018 and 2019 to 15 in 2026. The 2026 publications accounted for 18.99% of the total and represented the highest annual output. Publication output increased more noticeably after 2022.

Fig. 1 Annual publication trends in artificial intelligence research in corneal refractive surgery from 2018 to 2026



3.2 Distribution by Country, Institution, Author, and Journal

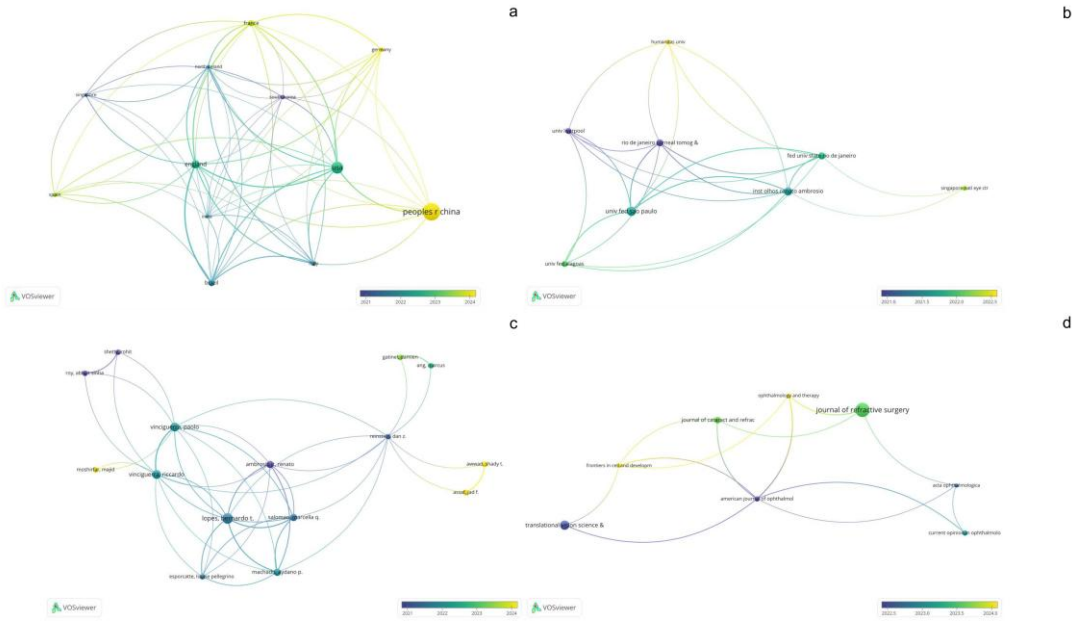
Country collaboration analysis showed participation from multiple countries. China and the United States occupied prominent positions in the international collaboration network and maintained collaborative links with multiple countries (Fig. 2a).

The institutional collaboration network included multiple cooperating institutions. Universidade Federal de São Paulo, Instituto de Olhos Renato Ambrósio, and Universidade Federal do Estado do Rio de Janeiro were among the more central institutions and maintained collaborative links with international institutions (Fig. 2b).

Several relatively concentrated research groups were identified in the author collaboration network. Vinciguerra P, Vinciguerra R, Lopes BT, Ambrosio Jr. R, Salomao MQ, and Reinstein DZ occupied prominent positions within the network (Fig. 2c).

The studies were published mainly in ophthalmology and refractive surgery journals. Journal of Refractive Surgery was a prominent publication venue. Journal of Cataract and Refractive Surgery, American Journal of Ophthalmology, and Acta Ophthalmologica also showed notable collaborative connections (Fig. 2d).

Fig. 2 Country, institutional, author, and journal analyses of artificial intelligence research in corneal refractive surgery. (a) Country collaboration network; (b) institutional collaboration network; (c) author collaboration network; (d) journal analysis

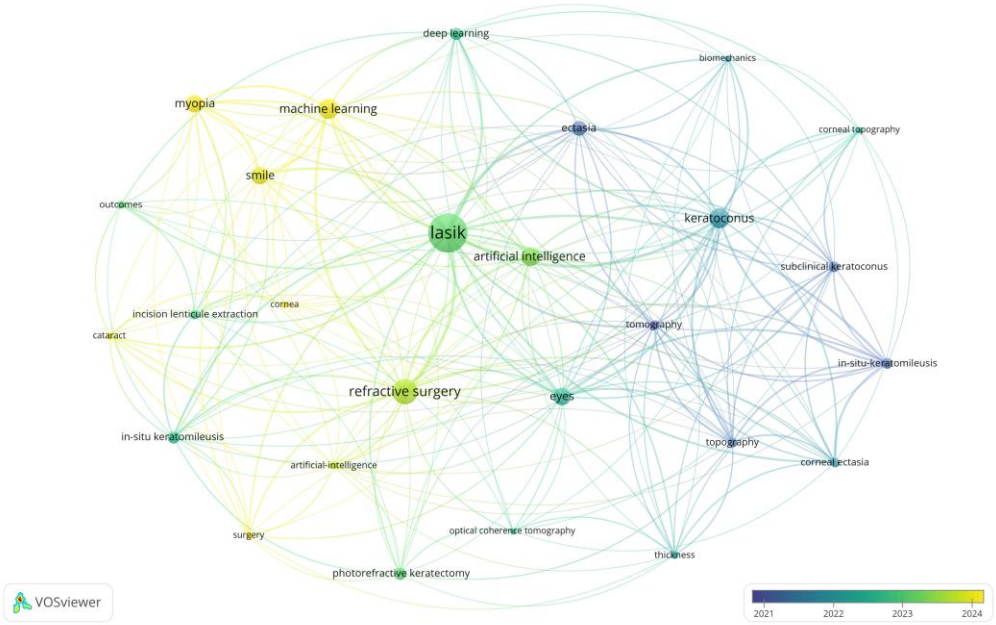


3.3 Keyword Co-occurrence and Temporal Evolution

The keyword network was mainly centered on refractive surgery, artificial intelligence, machine learning, deep learning, and LASIK. Keratoconus, corneal ectasia, corneal topography, tomography, and biomechanics were also prominent research themes. SMILE, photorefractive keratectomy, and optical coherence tomography appeared in relation to specific surgical procedures and imaging modalities.

Temporal overlay analysis showed that the earlier research focus was mainly on keratoconus, corneal ectasia, corneal topography, and biomechanics, whereas more recent keywords included machine learning, deep learning, SMILE, and OCT. The temporal distribution therefore showed a shift from corneal structural assessment and risk evaluation toward AI-based methods and procedure-specific clinical applications (Fig. 3).

Fig. 3 Keyword co-occurrence and temporal overlay visualization of AI research in corneal refractive surgery

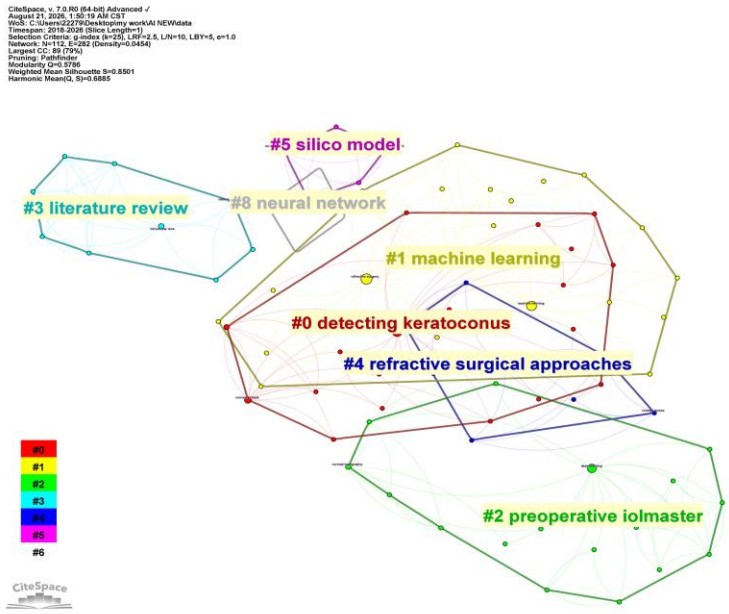


151

152 **3.4 Keyword Clustering Analysis**

153 The CiteSpace keyword network contained 112 nodes and 282 links, with a network
154 density of 0.0454. The largest connected component accounted for 79% of the
155 network. The clustering structure had a modularity of Q=0.5786 and a weighted mean
156 silhouette of S=0.8501, indicating a well-defined thematic structure (Fig.4).

157 **Fig. 4** CiteSpace-based keyword clustering analysis of AI research in corneal
158 refractive surgery.



159

160 The main clusters concerned keratoconus detection, machine learning, refractive
161 surgery and preoperative assessment, literature reviews, and refractive surgical
162 approaches. More recent clusters focused mainly on in silico models and neural
163 network applications, with a mean publication year of 2026.

164 **3.5 Research Frontiers**

165 Burst detection showed a shift in research focus from early themes of corneal
166 biomechanics and corneal topography toward multimodal corneal imaging, machine
167 learning methods, and procedure-specific applications. Laser vision correction had the
168 strongest burst intensity (1.11) during 2025–2026. SMILE and opaque bubble layer
169 showed sustained bursts from 2024 to 2026 (Table 2).

170 **Table 2** Major emerging keywords in AI-assisted corneal refractive surgery

Keyword	Burst strength	Burst period
Laser vision correction	1.11	2025–2026
Small incision lenticule extraction	0.81	2024–2026
Opaque bubble layer	0.81	2024–2026

Intraocular lens	0.96	2022–2024
Corneal cross-linking	0.77	2023–2024
Random forest	0.77	2023–2024
Multimodal corneal imaging	0.77	2022–2023
Corneal biomechanics	0.85	2020–2023
Corneal topography	0.82	2020–2022

3.6 AI-Related Research Characteristics Across Corneal Refractive Procedures

AI-related research showed different thematic patterns across the corneal refractive procedures examined. Keyword clustering and temporal evolution analyses showed that the studies mainly concerned LASIK, SMILE, and PRK/TransPRK. The main research directions were preoperative corneal risk assessment, detection of corneal abnormalities, and evaluation of postoperative visual outcomes.

3.6.1 LASIK-Related Research

LASIK-related research was relatively concentrated. Key terms included in situ keratomileusis, ectasia, corneal biomechanics, and corneal topography. The main research focuses were preoperative corneal safety assessment, corneal ectasia risk identification, and screening for corneal abnormalities.

3.6.2 SMILE-Related Research

SMILE-related research mainly concerned small incision lenticule extraction and SMILE. Key themes included the detection of subclinical keratoconus and other corneal abnormalities, corneal parameter analysis, and refractive outcome assessment. Clinical outcomes following SMILE also received increasing attention.

3.6.3 PRK/TransPRK-Related Research

Research on PRK/TransPRK was relatively limited and mainly concerned photorefractive keratectomy, corneal changes, and postoperative refractive outcomes. The reported topics included the relationship between procedure-related corneal

characteristics and visual and refractive outcomes.

4. Discussion

4.1 Global Research Trends

Research activity on artificial intelligence in corneal refractive surgery increased from 2018 to 2026, particularly after 2022, with the highest annual publication output observed in 2026. This growth may be related to advances in AI algorithms and the growing demand for greater precision in refractive surgery. At the same time, developments in machine learning and deep learning have expanded the use of AI for medical image analysis and clinical prediction. The increasing availability of multimodal data, including corneal topography, Scheimpflug tomography,[8]and biomechanical parameters,[9-11]has also provided a broader data basis for AI model development.

China and the United States occupied prominent positions in the international collaboration network, with collaborations extending across multiple countries. Further development of standardized databases and multicenter collaborations may help improve the generalizability and clinical applicability of AI models.[12]

4.2 The Role of Artificial Intelligence in Corneal Risk Assessment and Clinical Applications

Corneal ectasia risk assessment, keratoconus detection, corneal topography analysis, and machine learning models were among the major themes identified in the keyword co-occurrence, clustering, and burst analyses. These findings indicate that improving the safety of refractive surgery has been an important focus of AI research, particularly in preoperative risk stratification and the detection of corneal abnormalities.

Corneal ectasia remains a serious complication of corneal refractive surgery, and

pre-existing corneal abnormalities, including keratoconus, are important risk factors.[13]Conventional risk assessment is largely based on corneal topography, tomography-derived parameters, and clinical experience, which may be insufficient in some early or borderline cases.[14]AI-based approaches offer another way to combine morphological and biomechanical information. By learning from these parameters simultaneously, such models may detect patterns that are less apparent with conventional assessment and could assist in identifying patients at higher risk.[15]

The temporal pattern observed in our analysis also provides some insight into this development. Earlier research was more closely associated with corneal structural and imaging assessment, whereas more recent work has increasingly involved multimodal corneal imaging and machine learning. AI research in this field therefore appears to be moving beyond the detection of corneal abnormalities toward a wider range of clinical applications, including preoperative risk assessment and postoperative outcome evaluation.

4.3 Artificial Intelligence Applications Across Different Corneal Refractive Procedures

Our procedure-specific bibliometric analysis identified different patterns of AI applications across SMILE, LASIK/FS-LASIK, and PRK/TransPRK, reflecting differences in the clinical needs and technical characteristics of these procedures.

In LASIK and FS-LASIK, the literature has focused mainly on preoperative corneal safety assessment and the identification of corneal ectasia risk.[16]As LASIK involves flap creation and stromal ablation, assessing preoperative corneal structural stability remains an important research priority.[17]In recent years, AI models integrating corneal imaging, topographic, and biomechanical data have provided new approaches for improving risk identification.[18]

By comparison, AI research in SMILE, a rapidly evolving minimally invasive corneal refractive procedure, has focused mainly on screening for subclinical keratoconus and other corneal abnormalities, corneal parameter analysis, and refractive outcome assessment,[19]with increasing attention to clinical outcomes following SMILE. Previous studies have highlighted the importance of preoperative corneal characteristics in assessing the risk of ectasia after SMILE.[20]More recent studies have applied machine learning to surgical and corneal parameters to predict postoperative refractive outcomes.[19, 21]

Research on PRK/TransPRK was relatively limited and mainly addressed corneal changes and postoperative refractive outcomes, with a focus on the relationship between procedure-related corneal characteristics and visual and refractive outcomes.

Overall, these procedure-specific differences suggest that future AI development may benefit from tailoring models to the characteristics of individual procedures, data types, and clinical tasks to improve their clinical applicability.

4.4 Future Directions and Clinical Translation

Our Timeline and burst analyses indicate that research priorities have gradually expanded from the identification of corneal structural abnormalities toward machine learning, multimodal corneal imaging, and procedure-specific applications. Future research may increasingly focus on multimodal data integration, AI-assisted care across the clinical workflow, and clinical validation.[12]

Multimodal data integration may represent an important direction for future research.[9]Given the emerging interest in multimodal corneal imaging identified in our analysis, further studies could explore the integration of complementary corneal imaging modalities with clinical data. AI models incorporating corneal topography, anterior segment OCT, corneal biomechanics, and patient-specific characteristics may

ultimately enable continuous prediction from preoperative screening through postoperative follow-up.[15]

As research increasingly moves toward procedure-specific applications, AI may also support preoperative risk assessment, procedure-specific parameter analysis, and prediction of postoperative refractive outcomes.[18] Further multicenter, large-scale, prospective studies are needed to validate these models and establish standardized data and evaluation frameworks, thereby facilitating their translation into clinical practice.[12]

4.5 Strengths and Limitations

The main strength of this study is that it systematically characterized the development and knowledge structure of AI research in corneal refractive surgery and further compared research patterns across SMILE, LASIK/FS-LASIK, and PRK/TransPRK. Compared with previous studies that primarily addressed AI applications in ophthalmology as a whole,[9]our analysis provides further insight into procedure-specific differences in AI research, which may inform the development of more targeted clinical decision-support models.

Several limitations should be acknowledged. First, only English-language publications indexed in the Web of Science Core Collection were included, and relevant studies may therefore have been missed. Second, bibliometric analysis primarily characterizes research hotspots and knowledge evolution and cannot directly assess the clinical performance of AI models.[5] In addition, given the rapid evolution of AI, research trends may continue to change. Further multicenter clinical studies and prospective validation are therefore needed to determine the real-world clinical value of AI in corneal refractive surgery.

5. Conclusion

This bibliometric study systematically characterized the development, research hotspots, and evolving trends of artificial intelligence in corneal refractive surgery from 2018 to 2026. Research activity has increased steadily in recent years, with research priorities evolving from corneal topography, corneal biomechanics, and the identification of keratoconus and corneal ectasia risk toward machine learning, deep learning, multimodal corneal imaging, and procedure-specific clinical applications. Research priorities also varied across procedures: LASIK primarily focused on preoperative corneal safety and corneal ectasia risk assessment; SMILE increasingly addressed corneal abnormality screening, corneal parameter analysis, and refractive outcome assessment; whereas research on PRK/TransPRK remained relatively limited and mainly focused on corneal changes and postoperative refractive outcomes. With further advances in multimodal data integration, multicenter clinical research, and model validation, AI may play an increasingly important role in risk assessment, clinical decision-making, and personalized management in corneal refractive surgery.

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Declarations

Ethics approval and consent to participate

Not applicable. This study used publicly available bibliographic data and did not involve human participants, patient data, or animal experiments.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analyzed in this study were derived from the Web of Science Core Collection. The original records exported from the database and the dataset of 79 included publications are available from the corresponding author upon reasonable request.

Competing interests

The author declares that there are no competing interests.

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Authors' contributions

Y.L. conceived and designed the study, performed the literature search and screening, conducted data extraction and bibliometric analyses, and drafted and revised the manuscript. X.F. supervised the study and critically revised the manuscript. All authors read and approved the final manuscript.

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Not applicable.