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Impact of Artificial Intelligence on Ocular Biometry for Cataract: A Systematic Review

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Abstract

Artificial intelligence (AI) is a promising tool in the modernization of ophthalmic practice, particularly in ocular biometrics for cataract surgery. This review explores how AI can optimize the accuracy and personalization of human eye biometrics, which are crucial for diagnosis, surgical planning success, and the reduction of intra- and postoperative complications. The research was conducted through a systematic review using the PRISMA methodology across databases such as PubMed, Scopus, and Web of Science. Eight studies were included that met eligibility criteria, focusing on machine learning tools and other AI approaches. The results show that AI improves the prediction of biometric parameters, such as the power and position of intraocular lenses, in addition to identifying risk factors and optimizing resources, especially in contexts with limited infrastructure. AI-based models outperformed traditional methods, from advanced calculations to accessibility in remote regions. The review concludes that AI has transformative potential in ophthalmology, although challenges such as methodological validation, generalization, and ethical regulation remain. The study's implications include advancements in clinical practice and the need for public policies that promote the ethical and effective use of these technologies.

Keywords: Artificial intelligence; Cataract; Biometry; Intraocular lenses; Refractive error

Introduction

Cataract surgery is currently the most frequently performed surgical procedure worldwide. Since its early origins in ancient India, the technique, indications, and diagnostic approaches have continually evolved. Technological advancements – particularly the integration of artificial intelligence (AI) – have introduced significant innovations in ocular biometry, a fundamental step for accurate diagnosis, planning, and successful execution of the surgery. The incorporation of AI in biometric assessment enables greater precision in preoperative calculations, optimizing intraocular lens (IOL) selection and contributing to improved visual outcomes. Given its clinical relevance, AI-mediated biometry emerges as a promising and essential field of research for modern ophthalmologic practice(Clarke & Kapelner, 2020)(Zhou et al., 2023)(Li et al., 2020)(Connell & Kane, 2019). Ocular biometry consists of detailed measurements of the eye's anatomical structures, including axial length, anterior chamber depth, and corneal curvature–parameters indispensable for accurate IOL power calculation. However, in specific contexts, the application of machine learning-based algorithms extends beyond these measurements by offering broader analyses, such as detecting the presence or absence of cataract, identifying visual axis opacities, and evaluating the progression of anterior segment findings through comparative sequential imaging. These algorithms can also be customized–adapting biometric calculations for surgical planning to the individual anatomical characteristics of each patient by leveraging databases embedded within globally available formulas. While early detection supports diagnosis and appropriate referral for medical care, the personalized approach significantly reduces postoperative refractive errors, underscoring the transformative role of AI in enhancing clinical practice(Tabuchi et al., 2022)(Lanza et al., 2020). This study aims to systematically explore the available evidence, contributing to a comprehensive understanding of the applications and limitations of this technology in biometric and ophthalmologic practice.

Methods

This study presents a systematic review conducted in accordance with the guidelines of the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA)(Moher et al., 2009). The review protocol was prospectively registered in the PROSPERO database (registration number: 618761), ensuring transparency and methodological rigor. The initial stage consisted of a systematic search across three major and thematically relevant databases: PubMed, Scopus, and Web of Science. The selection of these platforms was based on their comprehensive coverage in biomedical and technological fields(Moher et al., 2009)(Higgins et al., 2021). The search strategy employed specific terms and Boolean combinations such as *"artificial intelligence," "machine learning," "ocular biometry," "axial length measurement,"* and *"intraocular lens calculation."* These terms were chosen to ensure the inclusion of studies aligned with the defined scope, focusing on the use of AI in ocular biometry.

Table 1: Question-structure based on PICO (Population, Intervention, Comparison, Outcome)

Component	Description
P (Population)	Patients requiring cataract surgery (e.g., confirmed by ophthalmological examination and diagnosis).
I (Intervention)	Ocular biometry.
C (Comparison)	Use of artificial intelligence to improve biometric calculations.
O (Outcome)	Clinically significant outcomes in the evaluation of biometric technique performance on cataract surgery results.

Inclusion criteria were defined based on literature and the need to select studies of high clinical relevance. Articles were accepted if they focused on the use of AI in biometric contexts specific to cataract surgery, considering technological advances and their clinical applications. The exclusion process, in turn, eliminated studies with inadequate methodological design, such as those addressing technological aspects without direct impact on clinical biometric practice. Thus, the methodology ensured that the analyzed evidence was scientifically grounded and relevant to the objectives of this research.

Search Strategy

A comprehensive search was performed in electronic databases including PubMed, Scopus, Web of Science, and EMBASE, covering the period from February 2020 to November 2024. MeSH terms and keywords related to the use of artificial intelligence in diagnostics, ophthalmic surgery, and biometric techniques were used, with a particular focus on cataract. The search strategy was adapted to each database, and reference lists of included studies were manually reviewed to identify potential additional articles.

Eligibility Criteria

Original studies that investigated the impact of artificial intelligence on ocular biometry or cataract surgery, published in English or Portuguese, were included regardless of study design. Exclusion criteria encompassed narrative reviews, editorials, conference abstracts, and studies not addressing the practical application of AI. All records identified in the databases were imported into EndNote software, where duplicates were removed. Initial screening was conducted by two independent reviewers who analyzed titles and abstracts based on predefined inclusion criteria. The search terms and their combinations included *"artificial intelligence," "machine learning," "biometry," "ocular biometry," "cataract surgery,"* and *"intraocular lens."* Keywords were applied to capture a broad range of articles relevant to the application of AI in ocular biometry, with a particular emphasis on cataract surgery. Potentially eligible studies were evaluated in full text for final inclusion. Discrepancies were resolved by a third reviewer.

Data Extraction and Analysis

Data from the included studies were extracted using a standardized form, which covered information on authors, year of publication, study design, target population, interventions involving AI, reported outcomes (e.g., biometric accuracy, postoperative visual outcomes), and main conclusions. Study quality was assessed using appropriate tools, such as ROBINS-I for observational studies or the Cochrane Risk of Bias Tool for randomized controlled trials. This rigorous approach ensures that the findings of this review provide a solid foundation for understanding the impact of artificial intelligence on biometric techniques applied to cataract surgery. 609 articles were initially identified. After the removal of 191 duplicate records, 418 studies remained for title and abstract screening. This step was essential to ensure that only studies relevant to the research question were included. Titles and abstracts were carefully examined using previously defined exclusion criteria, resulting in the removal of 331 articles that did not align with the scope of the study. Consequently, 87 studies were selected for more detailed evaluation through full-text reading to assess compliance with the eligibility criteria (Figure 1).

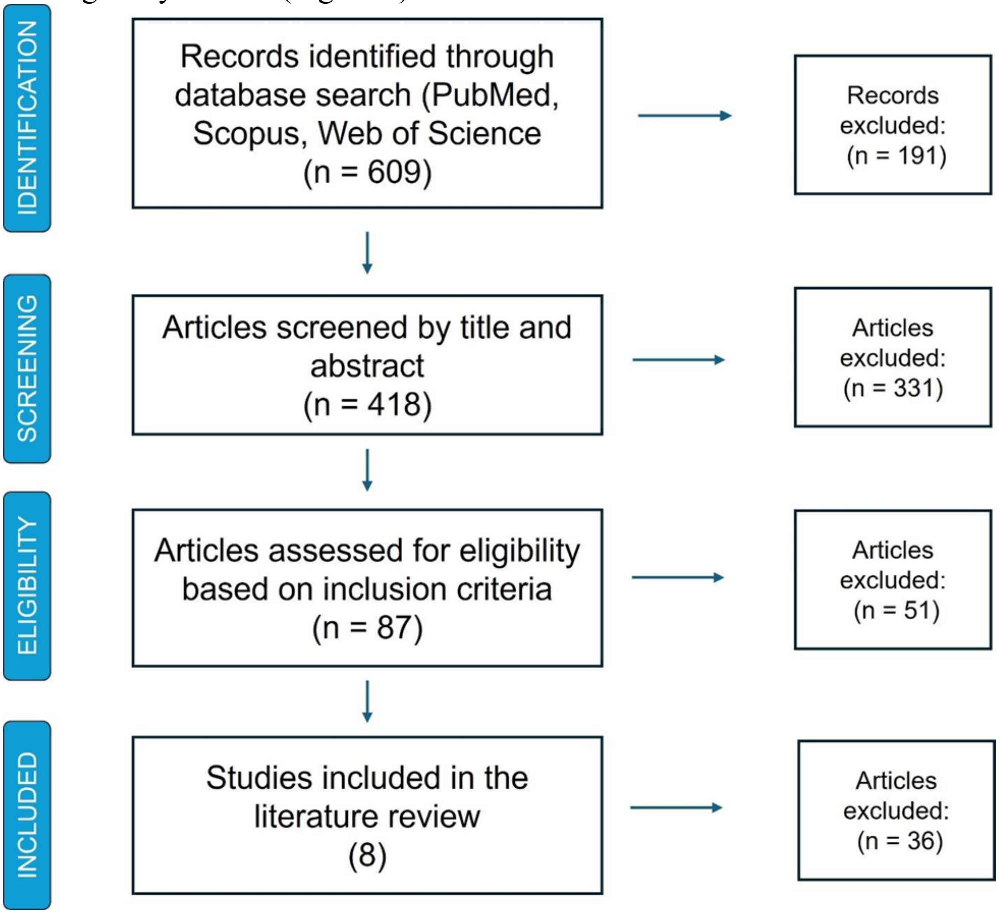

Figure 1: Flowchart of the study selection process according to PRISMA guidelines

This selection was justified by the need for robust evidence applicable to clinical practice, in line with widely accepted methodological recommendations, such as those described by Higgins et al., 2021. The process resulted in the selection of 8 studies that met all the inclusion criteria, forming the final corpus of this systematic review. Inclusion criteria were defined based on literature recommendations and the necessity to select studies of high clinical relevance. Articles were accepted if they addressed the use of AI in biometric contexts specific to cataract surgery, considering the technological advances and their clinical applications. Exclusion criteria, on the other hand, involved removing studies with inadequate methodological design or those dealing with technological themes lacking direct impact on clinical biometric practice.

Results

The selected studies evidenced the applicability of artificial intelligence (AI) in optimizing different stages of cataract management. Machine learning models were effective in predicting surgical complications and operative time based on individualized risk factors. AI algorithms trained with optical coherence tomography (OCT) images showed high precision in estimating preoperative visual acuity, reinforcing their utility in objective severity grading and prognostic evaluation. Furthermore, AI tools improved the prediction of intraocular lens (IOL) position and power, surpassing conventional formulas and enhancing surgical planning. Inventory management strategies based on AI also proved capable of optimizing IOL stock and minimizing refractive errors in outreach contexts. Collectively, the results underscore the clinical potential of AI in enhancing safety, accuracy, and efficiency in cataract surgery (Table 2).

Table 2: Summary of studies evaluating the application of artificial intelligence (AI) in cataract surgery

Author / Year	Objective	Methodology	Conclusion
Tabuchi et al. (2022) [5]	To demonstrate a real-time evaluation technology for cataract surgery using AI and compare surgical risk indicators between residents and experienced surgeons.	Cataract surgeries were performed by three residents and three experienced surgeons. Intraoperative risk indicators were measured in real time and statistically compared.	Risk indicators were significantly better in experienced surgeons, indicating that AI can objectively identify surgical risks and enhance the safety of cataract procedures.
Long et al. (2020) [9]	To develop an AI-based system for individualized prediction and telemedicine management of congenital cataract, integrating prediction with cloud-based follow-up.	The CC-Guardian system was developed using deep learning and Bayesian algorithms, validated through retrospective testing, and implemented on a cloud-based telemedicine platform.	The AI system enabled early detection of complications and reduced socioeconomic burden compared to conventional methods, showing potential in managing chronic ocular diseases.
Lanza et al. (2020) [6]	To evaluate ocular and systemic factors involved in cataract surgery complications in a teaching hospital using AI.	Data from 1,229 cataract surgeries were analyzed using AI, conducting 1.25 billion simulations to develop a personalized predictive model.	AI models effectively identified key risk factors (e.g., trainee surgeon, axial length, IOL power) and predicted surgical duration with high accuracy.

Yilmaz et al. (2024) [13]	To compare the effectiveness of AI real-time feedback versus expert instruction in technical skill acquisition in a randomized clinical trial.	Ninety-seven trainees were randomized into three groups: AI feedback, expert instruction, and no feedback. Performance was assessed using composite scores and blinded expert OSATS evaluations.	AI feedback led to better performance than no feedback and was comparable to expert instruction, suggesting AI's potential as a surgical training tool.
Ahn et al. (2022) [20]	To investigate the performance of an AI model using optical coherence tomography (OCT) images to estimate preoperative visual acuity in patients with senile cataract.	Retrospective study with cross-validation using 2,332 OCT images for training and 1,002 for testing. Assessed mean absolute error (MAE) and correlation between predicted and actual visual acuity.	The AI model demonstrated high accuracy in estimating visual acuity, showing promise as an objective tool to assess cataract severity and visual prognosis.
Li (2022) [3]	To develop and evaluate AI-based methods to improve prediction of intraocular lens (IOL) position and power in cataract surgery.	Data from 847 patients were used to train machine learning models for postoperative IOL position prediction and to improve existing and novel IOL power formulas.	AI-based methods outperformed traditional formulas in predicting IOL position and power, setting new standards for cataract surgical planning.
Brant et al. (2021) [19]	To evaluate discrepancies between planned and implanted IOL power in Ethiopian cataract campaigns using machine learning to optimize IOL inventory and reduce preventable refractive errors.	Patient data from Ethiopian cataract outreach were analyzed. A gradient descent model was applied to optimize IOL inventory, tested under different overstocking levels.	The ML model ensured >99.5% match to target IOL power using only 39% overstock. This suggests that inventory optimization can reduce refractive errors and operational costs.
Ahn et al. (2022) [22]	To evaluate the performance of an AI model using OCT images to estimate best-corrected preoperative visual acuity (BCVA) in senile cataract patients.	Retrospective study with cross-validation. Used 2,332 images for training/validation and 1,002 for testing. Ensemble model based on Inception-v4 and ResNet. Performance assessed via absolute error between estimated and real BCVA.	The AI model showed high precision in estimating visual acuity and cataract severity, supporting its use in objective preoperative assessment and outcome prediction.

Discussion

The selected studies provided robust evidence on the efficacy and applicability of artificial intelligence (AI) in ocular biometry for cataract care.

The CC-Guardian system exemplifies a significant advancement in the use of AI to optimize remote monitoring and predict complications in patients with congenital cataract. Based on Bayesian algorithms and deep learning models, this system achieved high sensitivity and specificity in detecting visual axis opacification and intraocular hypertension.

Additionally, it demonstrated cost-effectiveness and improvement in postoperative follow-up outcomes when compared to conventional methods (Long et al., 2020).

Similarly, AI was employed in a university hospital setting to identify variables associated with surgical complications, highlighting factors such as surgeon experience, axial length, and intraocular lens (IOL) power. The model not only demonstrated high accuracy in predicting surgical duration but also proved useful in personalizing intraoperative approaches and mitigating risk. In surgical training, a randomized controlled study compared real-time feedback provided by AI systems to in-person instruction from expert mentors during simulated procedures. Results showed that AI was as effective–or superior–in improving residents' technical skills, confirming its role as a high-impact educational tool. Lanza et al. employed AI on over 1,200 cataract surgeries to identify predictors of intraoperative risk. Variables such as axial length, surgeon experience, and IOL power significantly influenced complication rates. Their AI model also predicted surgical duration with a mean error <6 minutes (Ladas et al., 2021)(Sim et al., 2021).

Furthermore, AI-based systems for real-time intraoperative risk assessment have been implemented, improving accuracy in identifying surgical risks. These systems proved particularly beneficial for less experienced surgeons, reinforcing their value as training resources (Müller et al., 2024). AI-based platforms have also proven effective in training cataract surgeons by providing real-time feedback during simulated procedures and standardizing educational processes. Yilmaz et al. demonstrated that AI-based feedback systems for surgical training were as effective as expert-led instruction in skill acquisition (Chang et al., 2021).

Preoperative classification models have identified risk factors for poor outcomes, including comorbidities and low baseline vision (Yilmaz et al., 2024). Recent studies also highlight the potential of AI in predicting postoperative visual outcomes using preoperative data and identifying individualized risk factors (Lanza et al., 2021). Deep learning–based tools have proven effective in the early detection of cataract from ophthalmic images, increasing diagnostic accuracy and enabling earlier intervention (Brown et al., 2020).

Studies consistently show that AI-based formulas such as the Kane, Hill-RBF, XGBoost, and BART outperform legacy systems (Clarke & Kapelner, 2020) (Zhou et al., 2023) (Li et al., 2020) (Sim et al., 2021) (Ting et al., 2019). These models incorporate additional features–axial length, anterior chamber depth, lens thickness, central corneal thickness, gender–to personalize calculations (Clarke & Kapelner, 2020) (Ting et al., 2019). Vinogradov et al. reported AI-based models achieving 90–95% accuracy in predicting optimal IOL power (Mueller et al., 2016). Ladas et al. improved multiple formula generations by integrating AI for refractive target optimization (Ladas et al., 2021). However, Hill-RBF may show "out-of-bounds" warnings in unfamiliar biometric profiles (Ting et al., 2019). The XGBoost formula demonstrated exceptional accuracy in eyes with axial length ≥30.0 mm (Zhou et al., 2023). BART performed well even with incomplete datasets, a major advantage in real-world applications (Li et al., 2020). Models that integrate both clinical and imaging data have improved predictions, particularly in intraocular lens (IOL) power estimation (Long et al., 2020). In global outreach campaigns, AI optimized IOL inventories and reduced mismatches to <0.5%, with only 39% overstocking (Vinogradov et al., 2024). Additionally, AI has enhanced IOL power calculations, resulting in improved visual outcomes and greater patient satisfaction (Sim et al., 2021)(Brown et al., 2020).

Ahn et al. trained models using >2,000 anterior segment OCT images to estimate preoperative visual acuity with a correlation coefficient of 0.969 (Brant et al., 2021). These tools enable objective assessment of cataract severity and help tailor surgical expectations.

Based on the studies presented in the review table, artificial intelligence (AI) has led to significant advancements in multiple aspects of ophthalmic care related to cataract surgery. The reviewed evidence consistently demonstrates AI's transformative potential in diagnosis, treatment, and surgical education for cataract (Brant et al., 2021)(Ahn et al., 2022) (Asena et al., 2017). High predictive accuracy was observed in models assessing complications and visual acuity outcomes, alongside promising applications in training environments for ophthalmology residents (Ahn et al., 2022) (Thomsen et al., 2017).

However, methodological disparities remain. Some studies favored deep neural networks, while others employed simpler Bayesian models, reflecting variability in computational requirements and model generalizability. Significant differences in clinical characteristics and geographical contexts among studied populations further limit the direct application of findings across diverse healthcare settings. Moreover, logistical challenges and the high costs associated with real-time clinical implementation constrain scalability, particularly in resource-limited environments (Lanza et al., 2021)(Mueller et al., 2016)(Vinogradov et al., 2024).

Nonetheless, current research emphasizes persistent ethical and infrastructural barriers, such as the dependency on large volumes of high-quality data, which remain significant obstacles to large-scale implementation in routine clinical practice (Loftus et al., 2020).

Conclusion

This systematic review highlights that artificial intelligence (AI) represents a transformative milestone in ocular biometry, offering advanced solutions for diagnosis, treatment, and medical training in ophthalmology, particularly in the management of cataract. AI-based models have demonstrated effectiveness in the personalization of clinical approaches, prediction of complications, and evaluation of visual outcomes, with the potential to redefine standards of ophthalmic care. However, challenges related to methodological standardization, cost, and technological infrastructure continue to hinder broad implementation. In alignment with the existing literature, this analysis underscores the need for further studies involving diverse populations and fostering the integration of AI across different healthcare systems to ensure equitable access to technological innovations. Thus, AI not only holds promise for enhancing the quality of ophthalmologic care but may also contribute significantly to advancing health equity on a global scale.

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