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Original Research Article

Artificial Intelligence in Ophthalmic Surgeries: Current Applications and Future Directions

Dr Reem Javeed[1*], Dr Yugindu Raizada[1], Dr Renu Hashia Dhar[2], Dr Neharika Verma[3]

[1]Postgraduate Resident, Department of Ophthalmology, ASCOMS & Hospital
[2]Professor and Head, Department of Ophthalmology, ASCOMS & Hospital
[3]Senior Resident, Department of Ophthalmology, GMC Jammu

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Abstract: Artificial intelligence (AI) is revolutionizing ophthalmology, particularly in microsurgeries demanding precision. Current AI applications span the entire surgical process: candidate screening, surgery selection, postoperative prediction, and real-time intraoperative guidance. This integration is evident in refractive surgery, keratoplasty, cataract surgery, vitreoretinal surgery, and oculoplastic surgery. Beyond surgery, AI improves diagnostic accuracy for conditions like diabetic retinopathy, age-related macular degeneration, and glaucoma, while also enabling personalized treatment and enhancing service delivery via teleophthalmology and workflow optimization. The expanding scope of AI in ophthalmology signifies its maturation from analytical to interventional tools, aligning with a broader healthcare trend towards AI-augmented procedures. The success of AI in one area, such as precise intraocular lens (IOL) calculation, holistically influences subsequent surgical steps, maximizing AI's value across the patient journey. However, widespread adoption faces challenges including data privacy, algorithmic bias, lack of standardized metrics, limited public datasets, and integration complexities. Addressing these fundamental barriers is crucial for trust, equity, and practical implementation. Future directions emphasize enhanced multimodal AI models, integrated robotics, and expanded global health initiatives through teleophthalmology to address disparities and improve patient outcomes worldwide.

Keywords: Ophthalmic Surgery, Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Surgery Selection, Candidate Screening, Robot-Assisted Surgery, Cataract Surgery, Refractive Surgery, Vitreoretinal Surgery, Keratoplasty, Convolutional Neural Networks (CNN), Teleophthalmology.

INTRODUCTION

The widespread adoption of computer technology has propelled artificial intelligence (AI) into diverse fields, including healthcare. AI, encompassing machine learning (ML), deep learning (DL), and natural language processing (NLP), simulates human intelligence processes such as learning and reasoning. John McCarthy formally introduced the term "artificial intelligence" in 1956.

Over the last decade, AI's role in medicine has grown significantly, aiming to enhance patient care. Ophthalmology is particularly amenable to AI due to its heavy reliance on big data and image-based analysis. AI excels in early screening and identification of ocular conditions like diabetic retinopathy (DR), age-related macular degeneration (ARMD/AMD), and retinopathy of prematurity (ROP), especially through DL techniques like convolutional neural networks (CNNs) for pattern recognition in imaging data.

A growing body of literature explores AI in ophthalmic surgery, covering surgical candidate assessment, IOL power determination, robot-assisted surgery, and drug delivery for fundus diseases. Ophthalmic surgery is a complex microsurgery demanding meticulous precision. AI's ability to acquire and simulate extensive digital surgical data helps overcome human limitations, enhancing efficiency and accuracy. This transformative role allows AI to address challenges like surgeon shortages, potentially leading to new surgical paradigms. AI is rapidly becoming a fundamental instrument in ophthalmic surgery. The effectiveness of AI hinges on vast, high-quality datasets, highlighting the critical relationship where more data

***Corresponding Author:** Dr Reem Javeed
Postgraduate Resident, Department of Ophthalmology, ASCOMS & Hospital

enables more sophisticated AI applications. Despite AI's widespread use in ophthalmology, comprehensive reviews specifically addressing its application across all ophthalmic surgical subfields remain limited. This paper aims to provide a comprehensive insight into the current developments in artificial intelligence and ophthalmic surgery.

MATERIAL AND METHOD

This review synthesizes findings from multiple comprehensive literature reviews on AI in ophthalmology and ophthalmic surgery. The primary source conducted a PubMed and Google Scholar search for English-language documents published between 2018 and 2023. Keywords included "artificial intelligence" AND "ophthalmic surgery," alongside "surgical selection," "candidate screening," "robot-assisted surgery," "machine learning," "deep learning," "refractive surgery," "vitreoretinal surgery," and "keratoplasty," with MeSH terms and Boolean operators. All publication types except editorials and letters were considered, and bibliographies of relevant review articles were also explored.

Supporting literature reviews employed similar strategies. One on AI in cataract surgery (March-April 2024, PubMed, Google Scholar) included articles since 2010, using keywords like "artificial intelligence in cataract surgery," "ophthalmology," "deep learning," "machine learning," "convolutional neural networks," and "phacoemulsification." Both original articles and reviews were included. Another comprehensive review on AI in ophthalmology (PubMed, Google Scholar, IEEE Xplore, ScienceDirect) focused on peer-reviewed articles from 2013-2023. Search terms included "AI in ophthalmology," "machine learning in eye care," "deep learning in ophthalmic diagnosis," etc., with Boolean operators. Data extraction systematically collected information on study objectives, methods, AI techniques, findings, benefits, challenges, and recommendations, analyzed through qualitative synthesis and thematic analysis.

The consistent use of PubMed and Google Scholar across these sources confirms their authority in medical literature. Varying date ranges (2018-2023 for primary, since 2010 for one supporting, 2013-2023 for another) indicate the rapid evolution of AI in ophthalmology, with the narrower range in the primary source suggesting concentrated development in ophthalmic surgery specifically. The consistent exclusion of non-English articles is a potential limitation, possibly overlooking global advancements. However, the emphasis on empirical data, case studies, systematic reviews, or meta-analyses, and the exclusion of opinion pieces, reinforces a strong commitment to evidence-based reporting and academic credibility.

RESULTS

Ophthalmic surgery's intricate nature demands precision. AI's ability to acquire and simulate vast digital surgical data helps overcome human limitations, enhancing efficiency and accuracy. AI also mitigates surgeon shortages, financial constraints, complication risks, geographic barriers, and contagion hazards.

Current Applications of AI in Ophthalmic Surgery

Refractive Surgery: AI is integrated into refractive surgery for patient suitability assessment and complication prediction by analyzing corneal topography and biometry.

- **Candidate Screening:** AI models analyze clinical and optical data. Yoo *et al*., (2019) introduced an ML model for automated screening comparable to high-risk professionals. Xie *et al*., (2020) developed PIRSS, an AI model with 94.7% detection accuracy for suitable candidates from tomographic corneal imaging. Yoo *et al*., (2020) pioneered an interpretable ML model for expert-level laser surgery options, crucial for clinical trust and adoption.
- **Postoperative ICL Vault Prediction:** Kamiya *et al*., (2021) used ML (Random Forest Regression) on AS-OCT parameters, yielding fewer Mean Absolute Errors and higher percentage within target ICL vault range. Kang *et al*., (2021) developed a web-based ML application (XGBoost and lightGBM) for ICL vault prediction and optimal ICL size selection. Sun *et al*., (2022) introduced a fully automatic DL method using AS-OCT to monitor ICL position.
- **Postoperative Complication Prediction:** AI forecasts ectasia or myopic regression. Lopes *et al*., (2018) generated an AI model based on corneal topography with excellent accuracy for differentiating susceptible cases. Kim *et al*., (2022) devised an ML model (ResNet50 for image, XGBoost for data) to identify patients susceptible to myopia regression.

Keratoplasty (Corneal Transplantation): AI, through predictive algorithms and robotic techniques, is advancing keratoplasty.

- **Prediction of Future Keratoplasty:** AI assists in decisions between corneal collagen cross-linking (CXL) and transplantation. Yousefi *et al*., (2020) used unsupervised ML on OCT images to determine likelihood of future transplant, noting 68.7% for early-phase anterior ESI values without requiring annotation data. Ang *et al*., (2022) combined Random Survival Forest and Cox regression to analyze 10-year graft survival for DSAEK and PK, identifying diagnosis, procedure, and gender as crucial factors.

- **Robotic Surgery:** Keller *et al*., (2020) demonstrated feasibility of an industrial robot for OCT-guided corneal needle insertion in DALK, improving precision and safety. Savastano *et al*., (2022) showed feasibility of Symani Surgical System, a telerobotic technology, for suturing in corneal transplantation, with comparable results to manual methods but at a slower pace.

Cataract Surgery: AI is pivotal in optimizing postoperative visual outcomes, guiding surgeons, and assessing procedure effectiveness in cataract surgery.

- **Intraocular Lens Power Calculation:** AI-based IOL formulas enhance accuracy, especially for challenging cases. The Kane formula predicted 91% of refractive errors within ±0.50 D. The Karmona formula (SVM/MARS) and Hill-RBF 3.0 (regression/neural network) predicted errors within ±0.50 D at 98.38% and 93% respectively. The Ladas super formula (DL from five conventional formulas) predicted 69.8% within ±0.50 D.

Table 1: A Summary of AI-Based IOL Formulas

Formula	Basis of AI	Input Parameters	Post Operative Diopter Ratio (±0.50%)	Year	First Author
Clarke 38	Neural network	AL, K, ACDLT	Less proportion	1997	Clark GP
Ladas super formula39	DL based in five formular	AL, K, ACD	69.80%	2015	Ladas
Kane formula 40	Theoretical optics/regression	AL, K, ACDLT, CCT, Gender	91%	2019	Kane
Fullmonte	Neural network	AL, K, ACD, LT, CCT	Less proportion	2020	Clarke GP
Hill-RBF formula 3.043	Regression/ neural network	AL, K, ACD, LT, CCT, WTW, Gender	93%	2020	Hill
Karmona 42	SVM/MARS	Sim-K, AL, ACD, LT, WTW, IOL type	90.38%	2020	Gormona

Abbreviations: AL, Axial Length; K, Curvature; ACD, Anterior Chamber Depth; LT, Lens Thickness; CCT, Corneal Central Thickness; WTW, White to White Distance; IOL, Intraocular Lens.

his table highlights the diversity of AI techniques for IOL power calculation, providing quantifiable accuracy metrics and demonstrating temporal progression in AI formula development.

- **Robot-assisted surgery:** Bourcier *et al*., (2017) simulated cataract surgery with Da Vinci Xi Surgical System and robot-assisted phacoemulsification. Wilson *et al*., (2018) proposed IRISS, a robotic system with high tooltip accuracy (0.027±0.002 mm), successfully performing curvilinear capsulorhexis and entire cataract surgery.
- **Real-time Intraoperative Guidance:** AI platforms provide instantaneous feedback. Morita *et al*., (2019) developed a real-time video phase segmentation model using CNNs for cataract surgery (96.5% average correct response rate). Garcia Nespolo *et al*., (2022) combined computer vision and deep learning with a microscope for real-time audiovisual feedback, improving capsulorhexis symmetry. Ni *et al*., (2022) proposed SRBNet for surgical image segmentation. Wang *et al*., (2022) trained DeepSurgery, a deep learning algorithm for assessing and monitoring cataract extraction (90.30% accuracy), alerting surgeons to incorrect steps. Yoo *et al*., (2020) introduced a DL-based smart speaker to confirm surgical information pre-operatively, minimizing human errors.

Vitreoretinal Surgery: Vitreoretinal surgery involves procedures on the posterior eye.

- **Predicting Macular Hole Status:** AI models predict outcomes after vitrectomy and internal limiting membrane peeling (VILMP). Hu *et al*., (2021) developed a DL model predicting idiopathic MH status after VILMP with 84.7% accuracy (AUC 89.32%). Xiao *et al*., (2023) trained a multimodal deep fusion network model (MDFN) to reliably predict MH status one month post-VILMP (AUC 0.947). A fully automated 3D OCT image analysis DL model has also been developed for accurate MH parameter measurement.
- **Robot-assisted Vitreoretinal Surgery:** Edwards *et al*., (2018) first used a robotic surgical system (Preceyes) for human retinal surgery, enabling precise subretinal drug delivery. Gijbels *et al*., (2018) compared robotic versus manual epiretinal membrane (ERM) or internal limiting membrane (ILM) removal, finding the robot successful but slower. Gijbels *et al*., (2018) also developed a high-precision robotic device for retinal endovascular surgery (REVS), achieving high success rates in preclinical studies and first-in-

human use. Patel *et al*., (2020) demonstrated robot-assisted retinal vein cannulation improved stability.

Deep Learning (DL) algorithms demonstrate robust diagnostic capabilities in various surgical retina diseases:

- **Epiretinal Membrane (ERM):** Lo *et al*., (2020) show AUC 0.999, sensitivity 98.7%, specificity 98.0%. Tang *et al*., (2023) reported image-level accuracy of 95.65% and ERM region-level accuracy of 90.14%.
- **Retinal Detachment (RD):** Wang *et al*., (2024) achieved AUC 0.998, sensitivity 99.2%, specificity 99.8%. Fung *et al*., (2023) reported AUC 0.94, sensitivity 73.3%, specificity 96% for predicting anatomical outcomes. Li *et al*., (2024) demonstrated high precision (86.42%) and recall (83.27%) for lesion detection.
- **Macular Hole (MH) detection:** Valentim *et al*., (2024) reported accuracy from 88.5% to 91.4% and AUC from 90.2% to 95.5%. These consistently high metrics underscore AI's impressive diagnostic capabilities, crucial for successful surgical intervention.

Oculoplastic and Reconstructive Surgery: AI assists oculoplastic surgeons in devising rational surgical strategies.

- **Surgical Planning and Prediction:** Qu *et al*., (2022) proposed a multi-channel CNN algorithm for 3D eye structure images and pouch surgical plans, showing 98.78% reconstruction similarity. Song *et al*., (2021) devised a gradient-based decision tree (GBDT) for optimal ptosis surgical approach selection. Yoo *et al*., (2020) trained a generative adversarial network (GAN) to synthesize realistic postoperative appearances after orbital decompression for thyroid-associated ophthalmopathy (TAO), suggesting potential for predicting oculoplastic surgery results. Shao *et al*., (2023) presented an automatic system to measure TAO eyelid parameters (0.985 accuracy). Wang *et al*., (2022) used AI to segment orbital CT/MRI for endoscopic and 3D printing surgery.

These applications demonstrate AI's shift from diagnostic to active surgical participation, directly influencing surgical steps and augmenting human capabilities by addressing limitations in precision, stability, and subjective assessment.

CONCLUSION

This review comprehensively explores AI's utilization in ophthalmic surgery, highlighting its growing prominence and future expansion. Research in this field holds immense potential to advance ophthalmology, addressing the needs of numerous patients and generating substantial value for the medical economy by improving treatment success and minimizing recurrence. AI is not just a clinical tool but a strategic asset for healthcare systems, helping manage the burden of eye diseases and potentially reducing long-term costs.

Despite AI's robust integration into other surgical fields, its utilization specifically in cataract surgery is still in its infancy, though it shows clear applications across pre-operative (IOL calculation, diagnosis), intraoperative (smart operating theatre, workflow optimization, safety, training), and post-operative stages (scheduling, complication prediction). This varying maturity indicates that AI's adoption differs significantly between surgical subspecialties, possibly due to challenges in data standardization or generalizability within cataract surgery.

Numerous deep learning-based algorithms for automated diagnosis of medical and surgical retinal diseases showcase AI's significant promise. Overall, AI is revolutionizing ophthalmology by enhancing diagnostic accuracy, personalizing treatment, and improving service delivery across the board.

Future Direction

Despite the promising outcomes of AI in ophthalmic surgery, certain deficiencies persist, particularly concerning the increasing significance of personalized therapy. Personalized treatment is gaining substantial importance in ophthalmic surgery for patients with conditions such as myopia, cataracts, and presbyopia. This emerging direction holds immense potential for significantly enhancing patient outcomes, making it a fertile area for further exploration.

The future of AI in ophthalmology will be marked by the development of enhanced AI models capable of handling multimodal data. These models will integrate not only imaging data but also genetic information and comprehensive patient histories to provide more holistic views of a patient's health .This approach could identify genetic predispositions to eye diseases like age-related macular degeneration or diabetic retinopathy long before clinical symptoms appear, enabling earlier and more targeted interventions. Leveraging detailed patient history, including previous treatments and outcomes, will further refine AI models, allowing for personalized treatment plans that account for a patient's unique medical background. For instance, an AI system managing glaucoma could better predict disease progression and suggest personalized treatment adjustments by considering a patient's comprehensive medical history. This move towards multimodal data integration signifies a crucial step towards a more holistic, systems-biology approach to patient care, where richer data inputs lead to deeper understandings of disease mechanisms and more precise personalized treatments. Developing these advanced AI models will necessitate robust interdisciplinary collaboration among ophthalmologists, geneticists, bioinformaticians, and computer scientists, while carefully managing ethical considerations such as patient consent and potential genetic discrimination.

The integrative development of AI and surgical robots is anticipated to yield highly precise, minimally invasive, real-time, and intelligent operation control systems. AI will play a pivotal role in transcending the conventional master-slave control paradigm towards a more collaborative approach that incorporates neural network control. Enhanced robotic capabilities will integrate camera image information with other data sources, such as intraoperative OCT images and mechanical force sensing devices, enabling robots to better assist or even perform selected tasks during surgery. While robots may perform complex surgeries in the future, current technology cannot completely replace the clinical experience and surgical skills of doctors. This indicates a future of AI-augmented surgery rather than fully autonomous systems in the near term, where AI assists, plans, navigates, and supports, but the ultimate decision-making and nuanced skill remain with the human surgeon.

With the continuous development of 5G networks, remote surgery and education are expected to advance rapidly. Furthermore, recent advancements in large language models (LLMs) like ChatGPT offer significant opportunities and challenges in ophthalmic surgery. ChatGPT is particularly well-suited for low-risk writing tasks, such as summarizing clinically critical information in patient-friendly language for pre- and post-operative patient conversations. This not only saves ophthalmologists' time but also contributes to improving patient medical compliance and, consequently, surgical outcomes. If debugged and trained with extensive medical data, combined with rapid AI development, LLMs are likely to become powerful medical assistants, enhancing diagnostics and patient education, improving decision-making, and extending specialized care to underserved regions.

Global health initiatives leveraging AI-driven teleophthalmology services hold immense potential for addressing global eye health challenges, particularly in low-resource settings. These services can overcome geographical and infrastructural barriers by using AI algorithms to analyze retinal images taken with portable fundus cameras, identifying signs of diabetic retinopathy, glaucoma, or other eye conditions with high accuracy. This enables patients in remote areas to receive timely referrals and follow-up care, which is critical for preventing vision loss and managing chronic eye diseases. The recognition that deploying AI in low-resource settings requires a multi-stakeholder approach demonstrates a mature understanding of the broader implications for health equity. This is a critical factor: AI development cannot exist in a vacuum; its responsible deployment requires concerted societal effort. Effective deployment of AI solutions in such settings necessitates collaborative efforts among governments, non-governmental organizations (NGOs), and technology companies. Governments can establish supportive policies and invest in digital infrastructure, NGOs can assist in implementing and scaling programs and training local healthcare workers, and technology companies can provide expertise in AI development and tailored solutions.

However, several persistent challenges must be addressed for the continued integration and optimization of AI in ophthalmic surgery. There is a continuous need for larger, more diverse datasets, including those for complex and rare conditions, to refine algorithms. The lack of standardized deep learning metrics currently hinders the comparison and refinement of cataract surgery algorithms, necessitating the development of standardized protocols for AI applications in medical settings. Privacy and ethical concerns related to patient data use remain paramount, requiring robust data governance and ethical practices. Thorough validation is required for LLMs, and the lack of generalizability to novel datasets must be overcome. Finally, seamless integration into existing clinical workflows, enhancing adaptability, and ensuring user acceptance and adequate training for healthcare professionals are crucial. Making robotic systems more cost-effective and easier to maintain will also be vital for broader adoption.

REFERENCES

- Ahuja, A. S., Paredes III, A. A., Eisel, M. L., Kodwani, S., Wagner, I. V., Miller, D. D., & Dorairaj, S. (2024). Applications of Artificial Intelligence in Cataract Surgery: A Review. *Clinical Ophthalmology*, 2969-2975.
- Chatzimichail, E., Feltgen, N., Motta, L., Empeslidis, T., Konstas, A. G., Gatzioufas, Z., & Panos, G. D. (2024). Transforming the future of ophthalmology: artificial intelligence and robotics' breakthrough role in surgical and medical retina advances: a mini review. *Frontiers in Medicine*, *11*, 1434241.
- Hatamnejad A, Higham A, Somani S, et al. Feasibility of an artificial intelligence phone call for postoperative care following cataract surgery in a diverse population: two phase prospective study protocol. *BMJ Open Ophthalmol*. 2024;9(1):e001475
- He X, Handa J, Gehlbach P, Taylor R, Iordachita I. A submillimetric 3-DOF force sensing instrument with integrated fiber Bragg grating for retinal microsurgery. *IEEE Trans Biomed Eng*. 2014;61(2):522–534
- Lopes BT, Ramos IC, Salomão MQ, et al. Enhanced tomographic assessment to detect corneal ectasia based on artificial intelligence. *Am J Ophthalmol*. 2018;195:223–232.

- Moya T, Javaloy J, Montes-Mico R, Beltran J, Munoz G, Montalban R. Implantable collamer lens for myopia: assessment 12 years after implantation. *J Refract Surg*. 2015;31(8):548–556.
- Nuliqiman, M., Xu, M., Sun, Y., Cao, J., Chen, P., Gao, Q., ... & Ye, J. (2023). Artificial intelligence in ophthalmic surgery: current applications and expectations. *Clinical Ophthalmology*, 3499-3511.
- Olawade, D. B., Weerasinghe, K., Mathugamage, M. D. D. E., Odetayo, A., Aderinto, N., Teke, J., & Boussios, S. (2025). Enhancing Ophthalmic Diagnosis and Treatment with Artificial Intelligence. *Medicina*, *61*(3), 433.
- Tabuchi H, Morita S, Miki M, Deguchi H, Kamiura N. Real-time artificial intelligence evaluation of cataract surgery: a preliminary study on demonstration experiment. *Taiwan J Ophthalmol*
- Yoo TK, Ryu IH, Choi H, et al. Explainable machine learning approach as a tool to understand factors used to select the refractive surgery technique on the expert level. *Transl Vis Sci Technol*. 2020;9(2):8.

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