TRANSFORMING CATARACT AND REFRACTIVE SURGERY WITH AI AND DIGITAL TOOLS

A new era of precision, efficiency, and patient-centric care awaits.

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Modern cataract and laser vision correction (LVC) procedures require highly customized surgical plans to maximize outcomes. AI-driven tools can analyze complex diagnostic data, suggest the best surgical parameters, and even educate patients—all with greater speed and precision than traditional methods. Recent advances allow AI algorithms to outperform or augment human planning for tasks such as IOL calculations, the creation and refinement of refractive surgery nomograms, and risk assessment. At the same time, new digital platforms are streamlining preoperative workflow by integrating data and automating routine steps, allowing surgeons to focus on decision-making and patient care.

This article provides a comprehensive review of how AI and digital tools are transforming preoperative planning for cataract and refractive surgery. It discusses current applications that can improve accuracy and efficiency, software platforms and patient-facing tools that can enhance clinical workflow and surgical outcomes, and innovations likely to occur in the next 3 to 5 years.

AI-DRIVEN OPTIMIZATION OF SURGICAL PLANNING

Preoperative planning for cataract and refractive surgery involves deciding on the best surgical approach and parameters to achieve the desired visual outcome. AI-driven tools can assist surgeons in this effort by rapidly analyzing large datasets, including biometry, corneal topography, prior outcomes, and surgical preferences.

Cataract Surgery

Traditional IOL calculations are based on formulas that use linear regression on biometric measurements (axial length, corneal curvature, anterior chamber depth, etc). AI-based models can incorporate nonlinear relationships and high-dimensional data to improve the accuracy of refractive prediction. For example, the Kane formula employs an AI-derived algorithm that considers numerous biometric variables (including optional datapoints such as lens thickness and corneal thickness) to predict the postoperative refraction with greater accuracy than earlier-generation formulas.[1] Similarly, the Hill-Radial Basis Function (better known as the *Hill-RBF*) calculator is an artificial neural network IOL calculator trained on large datasets of surgical outcomes; the latest version (Hill-RBF 3.0) has been shown to have a predictive accuracy on par with or better than leading modern formulas such as the Barrett and Kane after its training data were expanded to cover a wider range of eyes.[2] A third approach is the PEARL-DGS formula, which uses machine learning modeling and outperformed benchmark formulas such as the Barrett Universal II when provided with detailed IOL design parameters.[3]

These data-driven formulas can reduce the likelihood of refractive surprises by generating more precise predictions of the effective lens position and postoperative refraction. Notably, AI-based models have been applied to challenging scenarios such as eyes with a history of refractive surgery where standard formulas often falter. An artificial neural network model by Koprowski et al learned to estimate the true corneal power from post-LASIK corneal tomographic data, reducing errors to approximately 0.16 D[4]—a level of precision that could improve outcomes in this difficult surgical situation.

Refractive Surgery

Refractive surgeons must interpret corneal topography/tomography measurements, wavefront analyses, corneal biomechanics, and other diagnostic test results to decide whether a patient should undergo LASIK, PRK, phakic IOL implantation, or a lens-based procedure. AI systems can synthesize these data to identify subtle patterns that could influence decisions. For instance, if inferior corneal steepening suggests early keratoconus, an AI algorithm might flag the patient as a poor candidate for LASIK and recommend CXL or a lens-based procedure instead.

Machine learning models embedded in refractive surgical planning software can help refine treatment nomograms. After each LVC case, the patient's achieved results (refraction, visual acuity, aberrations) are entered into the system, which then updates the nomogram. Over time, a surgeon-specific or clinic-specific nomogram is generated that accounts for systematic biases and optimizes treatment parameters.

Machine learning–based adjustments and rule-based expert systems operate in tandem. One component uses linear regression or more complex machine learning algorithms to fine-tune sphere and cylinder treatment (including the correction of higher-order aberrations), while rule-based AI software integrates data from topographers and aberrometers to determine whether advanced treatment (eg, topography-guided LASIK) is indicated and how to program it. This dual approach facilitates the creation of highly individualized refractive surgical plans, thereby improving the likelihood of achieving the target refraction and maximizing visual quality.

SOFTWARE PLATFORMS STREAMLINING PREOPERATIVE WORKFLOW

Comprehensive software platforms and digital tools are available to streamline preoperative consultations and planning. These systems can improve efficiency by automating data aggregation, instantly performing calculations, and facilitating real-time decision-making with patients. Cloud-based surgical planning software for cataract surgery such as the Zeiss Veracity Surgery Planner (Carl Zeiss Meditec) connects with diagnostic devices (biometer, topographer, OCT machine) and electronic medical records systems to compile a complete presurgical workup automatically. A surgical plan can be generated with just a few clicks of the mouse as the software pulls in all necessary measurements and runs multiple IOL power formulas or corneal astigmatism analyses in the background. The immediate feedback can save a clinic time and resources.

These platforms can also improve consistency and reduce errors by standardizing the planning process. The software can flag missing or inconsistent data (such as a keratometry disparity between devices) before a plan is finalized. Most systems also offer a comparison of multiple IOL formula results and suggest the best lens power or toric axis, which the surgeon may accept or adjust.

Carl Zeiss Meditec recently launched an AI-based IOL power calculator that works within the company's planning suite. This calculator can incorporate detailed lens design parameters (> 16,000 variables for each IOL model) to fine-tune its predictions, effectively making surgeon-specific A-constants obsolete. This sort of technology allows surgeons to explore different possible scenarios (eg, adjusting the target refraction or ablation profile) and the predicted outcome, which can be especially useful for complex cases or enhancements.

Before the surgeon sees a patient, AI-driven diagnostic tools can analyze imaging and test results. For instance, corneal topography and tomography devices often include built-in AI or rule-based algorithms to detect keratoconus and calculate an ectasia risk score. The Pentacam (Oculus Optikgeräte) generates several corneal indices and compares a patient's values against patterns of keratoconus from an internal database. The device can alert clinicians to subtle irregularities and grade disease severity. This type of AI-based screening can improve patient safety by identifying suspicious corneas.

These tools have the potential to streamline clinical workflow and may lessen staff workload in high-volume settings.

AI-ENHANCED PATIENT EDUCATION AND ENGAGEMENT

Informed Consent

The use of AI-based digital tools can enhance patients' understanding of the planned procedure, establish realistic expectations, and complete parts of the informed consent process. Researchers at Moorfields Eye Hospital piloted an AI-powered video consent process for cataract surgery.[5]

Generative AI technology such as the Synthesia platform (Synthesia) can create life-like avatar videos that explain the surgical procedure and its risks and benefits in the patient's preferred language. The content can be customized for different demographics.

In the pilot program, patients watched avatar videos during their preoperative visits or at home. Preliminary results indicated greater information retention with this method compared to written leaflets alone.[5] If further research bears out these early results, a single high-quality video could supplement or partially replace lengthy one-on-one consultations, thereby saving the surgeon and staff time.

Simulations

Many patients struggle to understand what to expect after cataract or refractive surgery. Personalized simulations can help. For example, the panfocal algorithm (CustomLens AI) predicts a patient's functional vision outcomes across different distances and lighting conditions. By analyzing large datasets of pre- and postoperative results as well as patient-reported outcomes, the algorithm can forecast the likelihood that a given patient will achieve spectacle independence at near, intermediate, or distance with a particular lens or strategy. Some platforms also leverage augmented or virtual reality to allow patients to visualize trade-offs (such as sharper near vision vs the possibility of halos).

Virtual Consultations

For cataract surgery, an AI-based telescreening platform can assess uploaded photos or optical data to confirm the diagnosis and urgency so that, when the patient meets the surgeon (virtually or in person), the discussion can focus on planning.

In refractive surgery, web-based algorithms can ask about the patient's visual needs and lifestyle as well as perform preliminary eligibility checks (eg, use self-reported prescription and age to suggest candidacy for LASIK vs lens surgery). By the time of the formal consultation, the surgeon has an AI-generated outline of the patient's goals and potential options.

FUTURE DIRECTIONS

Predictive Capabilities

The use of AI is being explored for predicting and preventing surgical complications. A study analyzing data from more than 1,200 cataract surgeries found that an AI model was able to identify key risk factors and predict overall surgical case duration with a mean error of under 6 minutes.[6] Further validation of these results is necessary, but such predictions could increase

OR scheduling efficiency and improve procedural safety by ensuring that the necessary tools are on hand.

Surgical Assistance

On the diagnostic front, AI-driven tools have already been approved for retinal applications. In the future, the technology may be able to analyze anterior segment OCT images for narrow angles or lens density to guide the timing of cataract surgery. In refractive surgery screening, more powerful AI models might be able to merge tomographic data with genetic and biomechanical data to predict the risk of ectasia with high accuracy. As datasets of outcomes grow, the technology could assist with patient selection for premium procedures. For instance, in the future, it may be possible to use AI to analyze a cataract patient's occupational visual needs, anatomic data, and personality factors (risk tolerance) to assess their candidacy for a multifocal lens.

An area of rapid development is fully integrated AI planning systems that function as virtual cooperating surgeons during the preoperative phase. For example, not only can the CustomLens AI platform calculate IOL power, but the system can also holistically recommend a surgical plan tailored to the patient. Platforms that complete beta testing and gain regulatory approval could become decision-support systems for cataract surgeons, who could enter a patient's data and receive an AI-generated plan to serve as a starting point. With widespread adoption, these systems could learn from a growing volume of cases (potentially via cloud updates pooling anonymized data from many centers) and offer better recommendations. Within 5 years, AI planning tools may be routinely incorporated into electronic health record systems and surgical microscopes, automatically populating a plan for the surgeon's review during the clinical exam.

Digital twins (ie, virtual replicas of patients' eyes) are another area of interest in ophthalmology. In the context of LVC, detailed ocular data are used to model how a specific eye would respond to various surgical interventions. With improved computational power and AI-driven biomechanical modeling, surgeons may soon run virtual surgery trials on a patient's digital twin before choosing a procedure. For example, LASIK and laser-assisted lenticule extraction could be simulated on a digital twin to determine which would provide a better postoperative quality of vision. This capability could become invaluable for complex and borderline scenarios. In the next few years, progress on AI-based corneal and lens modeling could yield clinical tools that can predict induced aberrations or lens position stability.

Patient Education

Chatbot technology and large language models (such as the ones behind advanced chat assistants) could be harnessed as virtual patient educators or navigators. In the future, a conversational agent on a clinic's website could respond to patients' questions about cataract surgery 24/7 with accurate, personalized information, freeing staff time and reinforcing the educational process. Early studies are comparing AI chatbot–generated explanations of cataract surgery with human-written pamphlets; the goal is to improve the readability and accessibility of patient materials.[7]

In the coming years, increasingly sophisticated chatbots may, with permission, be integrated with a patient's medical data to provide tailored advice. For example, the technology could remind a patient with high astigmatism why a toric IOL was recommended, guide them through preoperative instructions and presurgical workups (with reminders about drop regimens or fasting), and gather informed consent by ensuring all questions are answered interactively. This level of automation and personalization could enhance patient preparedness while greatly reducing the time clinicians spend on routine counseling.

Workflow

OR microscopes and femtosecond laser platforms could incorporate AI to register preoperative plans and guide execution automatically. Already, some laser cataract systems use AI-driven image recognition to guide corneal incisions and lens fragmentation patterns. In a few years, AI assistance may be able to adjust the laser or ultrasound energy settings on the fly based on intraoperative feedback. With enough data, algorithms could predict the duration of each cataract case and the equipment required, allowing operating lists to be arranged dynamically for maximum efficiency. This could help surgical centers manage a growing volume of cases without additional strain.

CONCLUSION

AI and digital tools are redefining preoperative planning for cataract and refractive surgery. The integration of AI into diagnostic devices and surgical planning software is steadily building a data-rich, feedback-driven ecosystem where each new procedure informs the next, continually refining the standard of care.

Innovations during the next few years are likely to make AI an indispensable partner in ophthalmic surgery. A responsible and evidence-based approach to these advances could usher in a new era of precision, efficiency, and patient-centric care in cataract and refractive surgery. ■

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