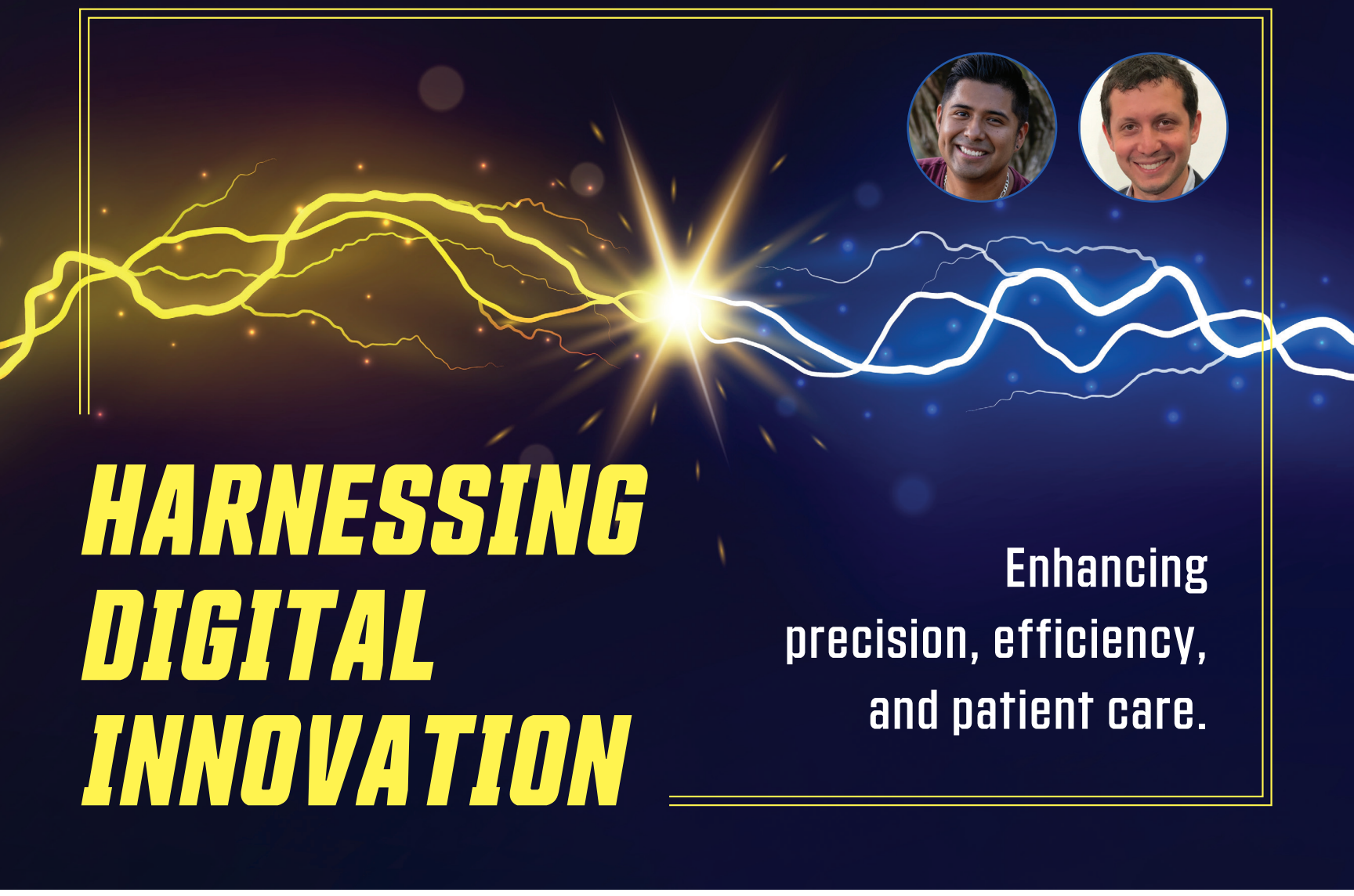

HARNESSING DIGITAL INNOVATION

Enhancing precision, efficiency, and patient care.

BY RICARDO TOCHIMANI, MS, AND ERIC D. ROSENBERG, DO, MSCENG

Although traditional ophthalmic surgery has been refined over decades, it remains heavily reliant on surgeon experience and skill. Digital integration is poised to disrupt this paradigm by introducing a layer of precision and data-driven insight to augment human capabilities in unprecedented ways. A range of technologies could be affected, including advanced intraoperative systems, robotic surgical platforms, and, critically, layered AI algorithms. When seamlessly integrated, these technologies could improve nearly every aspect of the patient journey and usher in a new era of personalized medicine.

AI IN THE SURGICAL WORKFLOW

Preoperative Care

Significant strides have already been made in the use of AI for cataract diagnosis and IOL power calculations. Machine learning and deep learning algorithms can analyze slit-lamp and fundoscopic images to increase the accuracy of diagnosis and cataract grading.[1-3] Even smartphone-based imaging—such as that captured with an iPhone 13 (Apple)—has demonstrated diagnostic accuracy comparable to that of experienced ophthalmologists, allowing the remarkably precise detection of cataracts and other anterior segment pathologies.[3,4] In regions with few specialists, this capability could facilitate the early detection of vision-threatening conditions and optimize patient triage.

AI can improve upon traditional vergence IOL formulas. AI-driven models—such as the Kane formula—incorporate biometric parameters, including axial length, keratometry, and anterior chamber depth, to enhance refractive accuracy and predict the effective lens position.[5,6]

Intraoperative Care

Integrating AI into the surgical workflow has the potential to improve outcomes. AI can provide real-time feedback on surgical technique, identify impending complications, and assess OR efficiency.

"Integrating AI into the surgical workflow has the potential to improve outcomes by providing real-time feedback on surgical technique, identifying impending complications, and assessing OR efficiency."

For example, technologies that recognize surgical instruments and detect cataract surgery phases can be combined with PhacoTracking—a machine learning–based analysis of surgical movements that is currently in development.[7] By capturing data such as instrument path length, movement count, and procedural duration, these technologies can generate valuable insights for training and OR optimization. Additionally, a personalized machine learning approach can alert surgeons to maneuvers or tools to avoid complications, thereby enhancing patient safety while providing targeted feedback that allows surgical skills to be refined.[8-10]

Surgical biomicroscopes, such as the Ngenuity (Alcon), Beyeonics One (Beyeonics Vision), and Artevo 800 (Carl Zeiss Meditec), have the potential to advance AI integration by superimposing critical information—such as patient demographics, digital markings for a precise capsulorhexis, and alignment cues—directly onto the surgeon's view. Coupled with the development of smart instruments capable of providing real-time haptic and auditory feedback, these technologies could help guide surgeons through procedures and alert them to excessive movements that may be indicative of intraoperative complications.[11]

AI-powered 3D biomicroscopes can analyze anatomic structures in real time to inform decisions regarding wound placement and IOL positioning.[5] Additional features, such as phaco settings and intraoperative variables (eg, elapsed surgery time and IOP), could be integrated to aid decision-making.

Surgical headsets provide high-fidelity 3D views of the surgical field.[12] They offer a visual experience that is comparable to or better than that provided by traditional biomicroscopes. Equipping these headsets with AI could refine visualization, improve intraoperative ergonomics, and enhance both surgical precision and efficiency.

Surgical Robotics

The development of robotic surgical assist systems is also an exciting frontier, but progress has been slower in cataract surgery than in other surgical subspecialties, primarily because of the microenvironment of the anterior segment and the high degree of precision required for these procedures. Cataract surgeons rely more on visual input than tactile feedback because the resistance and force required to sense tissue are often below the threshold for manual perception.[13] Although the robotic systems developed in 2020 focused primarily on stabilization, more recent platforms aim to assist with the surgical procedure itself.[12]

The Preceyes Surgical System (Preceyes) is currently the only ophthalmic robotic platform to have received the CE mark. Although it was initially developed for posterior segment applications—such as membrane peeling and subretinal gene injection—the system demonstrates potential for future use in anterior segment surgery. To the authors' knowledge, only two preclinical cataract surgical robots are in development as of this writing.

Although ophthalmic surgeons may lack traditional tactile perception with robotic systems, integrated sensors could detect subphysiologic tremor amplitudes and provide real-time corrections.[5,6] Coupled with next-generation digital surgical microscopes, these systems could introduce an amplified feedback loop previously unavailable in manual surgery. Ultimately, AI integration into surgical robotics could redefine surgical approaches, overcome inherent human limitations, and expand access to specialized ophthalmic care—particularly in remote areas where trained surgeons are scarce.

Electronic Health Records

Electronic health records and imaging software are becoming increasingly complex. AI has emerged as a critical tool for synthesizing and accessing patient data in real time. The demand on providers to see more patients in less time necessitates digital solutions that optimize both information dissemination and patient interactions. AI-driven systems can analyze and summarize key diagnostic data—such as OCT scans, visual fields tests, and IOP trends—to inform clinicians' surgical planning and decisions on follow-up care.

Some electronic health record platforms have already integrated generative AI for tasks such as responding to patient inquiries and generating encounter notes. In the future, AI may be able to generate patient summaries and offer real-time surgical guidance, while ensuring that physicians retain control over critical decisions. The ethical use, storage, and security of patient data, however, must remain a priority as technology evolves.

THE FUTURE OF CATARACT SURGERY

The adoption of AI-driven software in cataract surgery creates an opportunity to streamline surgical workflow—from preoperative assessment to postoperative evaluation. By reducing manual data entry and transcription errors, AI has the potential to improve efficiency and enhance patient outcomes. As the demand for cataract surgery rises, the early adoption of digital solutions could enable clinics to manage increasing patient volume without compromising the quality of care.

The widespread adoption of AI technology depends on physician acceptance, education, and, most critically, reimbursement policies. Securing buy-in from governmental agencies and insurance payers remains a significant hurdle because the integration of new technologies across health care systems is often subject to economic and regulatory considerations. Overcoming these challenges is essential to realizing AI's potential in ophthalmic surgery. ■

1. Shimizu E, Tanji M, Nakayama S, et al. AI-based diagnosis of nuclear cataract from slit-lamp videos. *Sci Rep*. 2023;13:22046.
2. Son KY, Balntas V, Chen D, et al. Deep learning-based cataract detection and grading from slit-lamp and retro-illumination photographs. *Ophthalmol Sci*. 2022;2(2):100147.
3. Ueno Y, Oda M, Yamaguchi T, et al. Deep learning model for extensive smartphone-based diagnosis and triage of cataracts and multiple corneal diseases. *Br J Ophthalmol*. 2024;108:1406-1413.
4. Tey KY, Cheong EZK, Ang M. Potential applications of artificial intelligence in image analysis in cornea diseases: a review. *Eye Vis (Lond)*. 2024;11(1):10.
5. Ahuja AS, Paredes AA III, Eisel ML, et al. Applications of artificial intelligence in cataract surgery: a review. *Clin Ophthalmol*. 2024;18:2969-2975.
6. Gutierrez L, Lim JS, Foo LL, et al. Application of artificial intelligence in cataract management: current and future directions. *Eye Vis (Lond)*. 2022;9(1):3.
7. Smith P, Tang L, Balntas V, et al. "PhacoTracking": an evolving paradigm in ophthalmic surgical training. *JAMA Ophthalmol*. 2013;131(5):659-661.
8. Al Hajj H, Lamard M, Cochener B, Quellec G. Smart data augmentation for surgical tool detection on the surgical tray. *Annu Int Conf IEEE Eng Med Biol Soc*. 2017;2017:4407-4410.
9. Lindegger DJ, Wawrzynski J, Saleh GM. Evolution and applications of artificial intelligence to cataract surgery. *Ophthalmol Sci*. 2022;2(3):100164.
10. Nuliqiman M, Xu M, Sun Y, et al. Artificial intelligence in ophthalmic surgery: current applications and expectations. *Clin Ophthalmol*. 2023;17:3499-3511.
11. Miehle J, Ostler D, Gerstenlauer N, Minker W. The next step: intelligent digital assistance for clinical operating rooms. *Innov Surg Sci*. 2017;2(3):159-161.
12. Alafaleq M. Robotics and cybersurgery in ophthalmology: a current perspective. *J Robot Surg*. 2023;17:1159-1170.
13. Garcia Nespolo R, Yi D, Cole E, et al. Evaluation of artificial intelligence-based intraoperative guidance tools for phacoemulsification cataract surgery. *JAMA Ophthalmol*. 2022;140(2):170-177.

ERIC D. ROSENBERG, DO, MSCENG
- Cornea and complex anterior segment surgeon, SightMD, Babylon, New York
- Assistant Professor, New York Medical College, Valhalla, New York
- Cofounder, Digital Ophthalmic Society
- Member, *Bookmarked** and Eyetube** Editorial Advisory Boards
- ericr29@gmail.com
- Financial disclosure: Consultant (Alcon, Bausch + Lomb, BVI Medical, Carl Zeiss Meditec)

RICARDO TOCHIMANI, MS
- Medical student (class of 2026), New York Medical College, Valhalla, New York
- rtochima@student.nymc.edu
- Financial disclosure: None

**Bookmarked* is a sister publication to *CRST*.
**Eyetube is powered by Bryn Mawr Communications, parent company of *CRST*.