# ROBOTICS IN RETINAL SURGERY:

## RECENT ADVANCES AND APPLICATIONS

### Researchers are making strides to integrate new tools to help surgeons in the OR.

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Robotic technology is reshaping the landscape of vitreoretinal surgery, driven by the need for micrometer-scale precision and stability that often exceed the limits of human dexterity.[1,2] The retina's fragile anatomy and the technical demands of vitreoretinal procedures such as membrane peeling, subretinal injection, and vascular cannulation have led to the development of specialized robotic platforms.[3-8]

Advances in robotic control, intraoperative imaging, and microsurgical instrumentation have begun to redefine what is possible in retinal surgery.[5,9] In this article, we highlight several innovations that mark a transition from proof-of-concept engineering to clinical tools, offering stability, precision, and safety for the most delicate retinal procedures.

#### PRECEYES SURGICAL SYSTEM: FIRST-IN-HUMAN EXPERIENCE

One of the earliest robots to enter the retinal space, the Preceyes Surgical System (Carl Zeiss Meditec), demonstrated precision better than 20 µm and tremor-free control, proving robotic microsurgery feasible and safe.[6,7,10,11] In 2018, this system became the first remotely controlled robotic platform to successfully perform surgery inside the human eye.[6] The device has received CE marking in Europe,[12] and New York Eye and Ear is collaborating with Preceyes/Carl Zeiss Meditec to pursue FDA approval.[13]

In practice, the surgeon is positioned at the usual surgical site and operates from a console equipped with a joystick-style controller, which translates hand movements to the robotic arm holding the intraocular instruments positioned at the ocular entry site through standard 23-, 25-, or 27-gauge sclerotomies (Figure 1).[12]

Randomized and first-in-human trials demonstrated successful robot-assisted membrane peeling and subretinal injections, achieving anatomic and functional outcomes comparable with manual surgery.[3,6-8,14,15]

#### AT A GLANCE

- Advances in robotic control, intraoperative imaging, and microsurgical instrumentation have begun to redefine what is possible in retinal surgery.
- The Preceyes Surgical System (Carl Zeiss Meditec), OQrimo (Riverfield), ORYOM (Forsight Robotics), and others have shown promise for automating membrane peeling, subretinal injection, and vascular cannulation.
- Limitations to the adoption of robotics in retina include high upfront and ongoing costs, limited commercial availability, and lack of differentiated reimbursement.

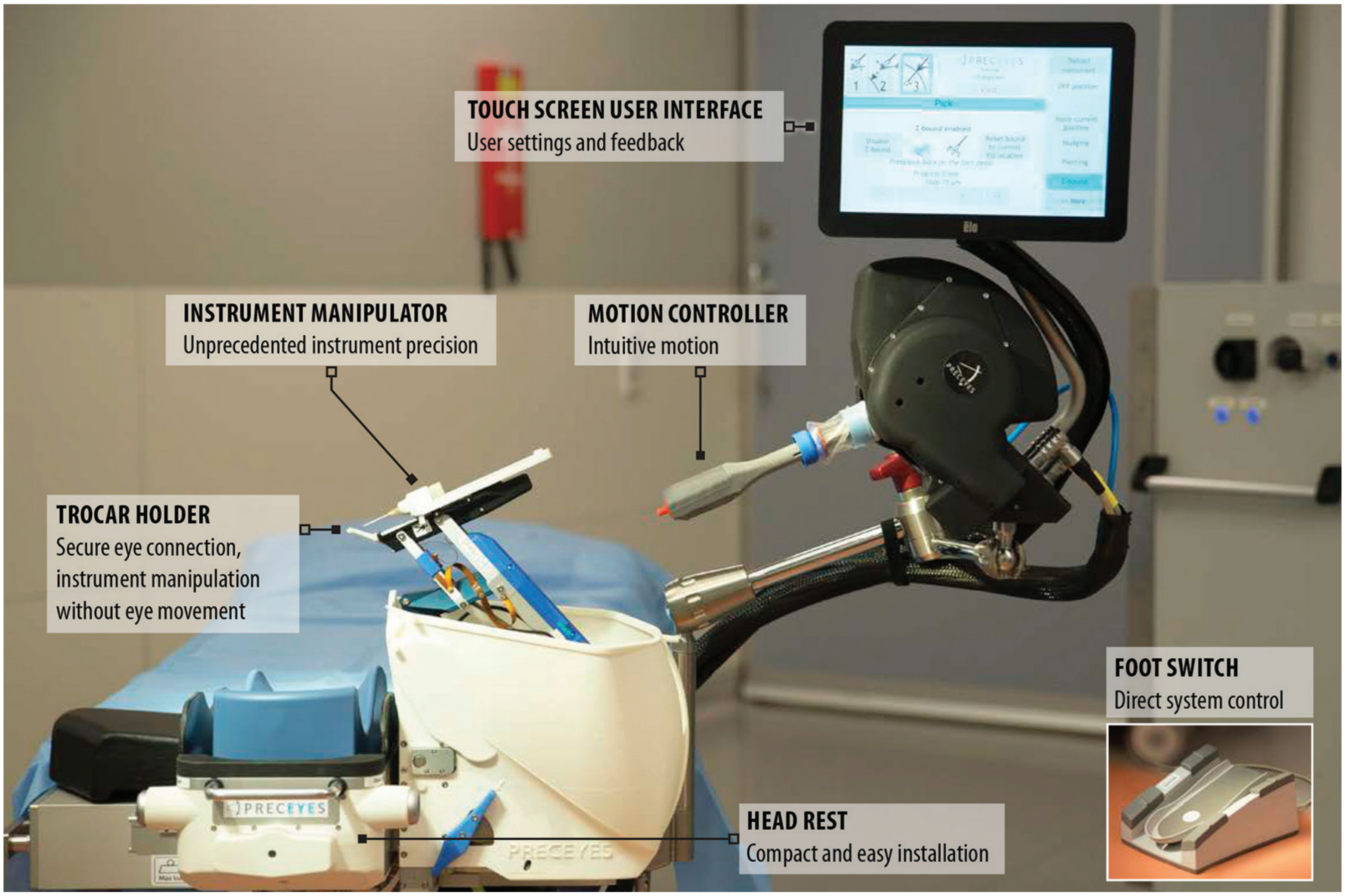


Image courtesy of Carl Zeiss Meditec

Figure 1. The Preceyes Surgical System, a telemanipulation robotic platform designed for intraocular microsurgery, includes a robotic arm that holds intraocular instruments.

Robot assistance also enabled stable cannulation and controlled subretinal drug delivery without increasing microtrauma or adverse events.[6,7,14] Integration of intraoperative OCT-based distance sensors further enhanced depth control and safety.[14] Experimental animal studies showed consistent retinal vein cannulation and targeted delivery of agents such as ocriplasmin for retinal vein occlusion.[10] Surgeons reported reduced fatigue and improved precision with experience, although procedures took longer during the learning phase.[16]

## OQRIMO: A ROBOTIC ENDOSCOPE HOLDER

Visualization challenges, particularly in eyes with corneal opacity, small pupils, or intraocular tumors, have long limited surgical efficiency. In 2021, researchers in Japan created the Eye Explorer robotic system to stabilize and manipulate an endoscope, allowing for bimanual surgery. The device balances its own weight to prevent accidental drops and provides a wide intraocular field of view (horizontal 118°, vertical 97°). By reducing external force on the eye by more than 15% compared with manual handling, the Eye Explorer may also reduce the risk of iatrogenic injury.[17]

Building on this success, OQrimo (Riverfield) became the first clinically approved ophthalmic endoscope-holding robot in Japan in 2023 (Figure 2).[5] OQrimo is designed to enhance stability through a gimballed structure that allows the endoscope to pivot smoothly while remaining steady and properly oriented. The endoscope can be positioned at the desired surgical site using a foot pedal control, and it comes with automatic safety withdrawal.[5,18]

In a prospective study of seven eyes undergoing vitrectomy, the OQrimo endoscope-holding robot assisted trocar placement in eyes with long axial lengths. Two trocars were placed 3.5 mm to 4.0 mm from the limbus at the 2 and 8 clock positions.[19] The OQrimo-stabilized endoscope, inserted through the 2 clock hour port, allowed direct visualization of the contralateral pars plana for precise third trocar insertion near the ora serrata. No clinically significant complications occurred, supporting the system's short-term safety for intraocular use.[19] Ongoing work in Japan is exploring its integration into complex vitreoretinal procedures.[5]

## HEAD-MOUNTED ROBOT FOR SUBRETINAL INJECTION

A 2025 study by Posselli et al introduced a head-mounted robot designed to improve the safety and precision of subretinal injections. The lightweight device

Image courtesy of Riverfield

Figure 2. OQrimo, approved for use in Japan in 2023, uses a robotic arm to maneuver and stabilize an endoscope, allowing for bimanual surgery.

Image courtesy of Acusurgical

Figure 3. Dr. Nerinchkx uses the Luca robot during retinal surgery at the Ghent University Hospital in Belgium.

(0.8 kg) attaches to a custom-fitted headpiece that moves with the patient's head to keep the eye and robot perfectly aligned during small movements or breathing.[20]

Using a hybrid ex vivo/in situ model with enucleated porcine eyes mounted on human volunteers, investigators demonstrated < 1 µm positioning accuracy and consistent cannula placement even with simulated head motion. In 21 subretinal injections performed at a low flow rate (0.18 mL/min), the system achieved 100% bleb formation success, compared with an approximately 64% success rate with manual techniques.[20,21] These results suggest head-mounted robotic assistance could enable safer, more reproducible subretinal injections under conscious sedation.[20,21]

## OTHER PLATFORMS ON THE HORIZON

The ORYOM system (Forsight Robotics) introduces a remote, 3D-based control to ophthalmic surgery. Surgeons operate through a console while the robot performs precise, tremor-free maneuvers. Although its first target is cataract surgery, its core technology could migrate to vitreoretinal procedures requiring similar precision.[22,23]

The Intraocular Robotic Interventional and Surgical System, designed by researchers at the University of California Los Angeles, uses dual robotic arms that handle standard microsurgical instruments for anterior and posterior segment procedures. The system, which uses joystick bimanual control and integrates OCT for semiautomated precision, is designed to allow quick instrument exchange using conventional intraocular tools.[24] Early studies demonstrated successful performance of capsulorhexis, lens removal, and retinal vein cannulation in ex vivo porcine eyes.[25,26] Notably, it was the first robot to complete an entire cataract surgery mechanically.[24]

Ophthorobotics is a company targeting one of the most common retinal interventions: intravitreal injections. The device mounts on the patient's head, identifies the pupil, and performs automated pars plana injections under supervision. Animal studies demonstrated accurate placement, suggesting automation may one day feasibly reduce clinician workload in high-volume injection clinics.[5,24,27]

Weighing just 306 g, RAM!S (Technical University of Munich) is a palm-sized robot that is designed to deliver 5 µm positional accuracy and has successfully executed subretinal injections in experimental models.[5,24,28] Its compact design could make robotic assistance practical even in small surgical suites.

Unlike the mechanical actuation used for most robots, OctoMag (ETH) employs magnetic fields to steer a wireless microrobot inside the eye, which has achieved vein cannulation in animal models.[29,30]

The Acusurgical Luca robot uses two robotic arms controlled by the surgeon from a pilot station (Figure 3). The system is designed to provide precision up to 10 µm for full vitreoretinal surgeries such as vitrectomy.

At the 2025 Retina World Congress, Fanny Nerinckx, MD, presented early results from six patients who underwent robotic surgery for macular pathology. The procedures—vitrectomy with the induction of a posterior vitreous detachment—were successful with no device-related adverse events.[31] A European trial (NCT06294613) is recruiting up to 15 patients undergoing vitreoretinal surgery for macular pucker.

## LIMITATIONS OF CURRENT ROBOTIC PLATFORMS

The costs, limited commercial availability, and lack of differentiated reimbursement make adoption of robotic systems financially challenging. If reimbursement remains equivalent to manual surgery, robotic procedures are not currently cost-effective. Existing cost-utility analyses in retinal surgery still focus solely on traditional procedures such as pars plana vitrectomy, scleral buckle, and pneumatic retinopexy, excluding robotic platforms.[32-34]

In addition, technical and workflow challenges hinder integration. Robotic systems often introduce longer operative times and require a steep learning curve.[6,15,35,36] The need for specialized training, standardized credentialing, and integration into the workflow adds logistical complexity.[9,37-39] Space constraints in the OR are also a consideration; the Preceyes system, for instance, requires an additional foot pedal, adding to the existing microscope, laser, and vitrector pedals.

Ergonomically, the surgeon's hand position is offset while maintaining visualization through the microscope, which may be less intuitive than conventional manipulation. Many surgeons are accustomed to tactile feedback and may be reluctant to adopt robotic systems that alter hand-eye coordination.

Institutional investment decisions likely depend on cost savings, safety benefits, and clear workflow compatibility.

## THE ROAD AHEAD

Ophthalmic robotics have moved rapidly from experimentation to real-world feasibility. The next phase will require addressing economic and logistical hurdles, including workflow integration, training, and cost. As technology continues to miniaturize and integrate with intraoperative OCT and imaging guidance, robotic platforms may soon extend the limits of human dexterity, enabling safer, more reproducible procedures for complex vitreoretinal and subretinal therapies. The promise of the coming decade is not to replace the surgeon, but to enhance the surgeon's precision, endurance, and confidence in the most delicate corners of the eye. ■


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