



Robotics in the Retina OR

Vitreoretinal surgery is entering a new phase with the advent of robots for observation and manipulation.

BY SHINTARO NAKAO, MD, PHD; KOTARO TADANO, PHD; AND KOH-HEI SONODA, MD, PHD



The recent growth of robotics in the surgical field has been remarkable. For example, the da Vinci surgical system

(Intuitive Surgical) was a significant advancement in the field of urology, and it is now used in many fields, including gastrointestinal surgery, gynecology, respiratory surgery, and cardiac surgery.¹ Some estimate that the global robotic surgery market will grow approximately four-fold by 2030.²

However, the accuracy of the da Vinci system is reported to be 1 mm, which is insufficient for vitreoretinal surgery,³ and a robotic system dedicated to vitreoretinal surgery remains elusive. Researchers have been working on robotics in the field of ophthalmology since the late 1990s.⁴ Because vitreoretinal surgery is performed in the very limited space of the vitreous cavity, delicate and precise procedures are required. The human hand is also limited in terms of the agility, tremor cancellation, and precision required for vitreoretinal surgery. Thus, highly accurate robotic surgery could be suitable for vitreoretinal surgery.

ROBOTICS RUNDOWN

Current robotic surgery systems in ophthalmology can be broadly classified as operation systems, operation assistance systems, or observation systems.⁵

Operational robots are the most common. Ueta et al investigated the positioning accuracy of a robotic prototype for vitrectomy and reported that the system achieved a positioning accuracy of about 30 μm , which is approximately 1/10 to 1/5 of manually conducted accuracy.⁶ In animal models, the researchers succeeded in creating a posterior vitreous detachment and retinal vessel micro-cannulation.

Edwards et al conducted a first-in-human study of remotely controlled robot-assisted retinal surgery using the PRECEYES surgical system (Carl Zeiss Meditec).⁷ They found that membrane peeling took longer with a robotic system than with manual surgery, but they were also able to perform subretinal injection of recombinant tissue

plasminogen activator for subfoveal hemorrhage secondary to wet AMD.^{7,8}

A number of other telemanipulated robotic systems have been developed that show promise in providing intraocular dexterity when positioning microstents and grippers and maneuvering forceps during membrane peeling (with a precision better than 5 μm).⁹

Several operation assistance systems are under development, including handheld robotic surgical tools for controlling tremor, force sensing, and intraocular dexterity.^{9,10} Researchers are also working on a passive support robot for ophthalmic surgery, which is a commercially available system that was customized for ophthalmic surgery.¹¹ The robot stabilizes the elbow and arm, making it possible to perform more stable procedures in continuous curvilinear capsulorhexis and suturing.¹¹

ROBOTS IN THE OR

Although advances in endoscope technology enable detailed observation of tissues under the iris that cannot be observed with conventional systems, an endoscope is not a widely used tool in vitrectomy.¹² This is due, in part, to the fact that the surgeon must operate it, as the operative field

AT A GLANCE

- ▶ Current robotic systems in ophthalmology are broadly classified as operation systems, operation assistance systems, or observation systems.
- ▶ Several operation assistance systems are under development, including a robot for controlling tremor and a passive surgery support robot for ophthalmic surgery.
- ▶ The authors developed an observation robot to hold an endoscope, which is approved as a medical device in Japan.



Image courtesy of Riverfield



Figure. The surgeon operates the endoscope-holding robot using a foot switch while viewing the endoscope screen.

of ophthalmic surgery is too small for an assistant to hold it.

Based on this unmet need, our team developed an observation robot (OQrimo, Riverfield) to hold an endoscope, which was approved as a medical device in Japan in April (Figure).¹³ An operator moves the robotically controlled endoscope with the foot switch, and the robot is designed with a safety function to withdraw from the eye when a certain amount of external pressure is applied.

The robot may be useful during surgical scenarios that warrant a bimanual technique, such as the treatment of fibrous membranes in proliferative retinopathies, particularly anterior hyaloidal fibrovascular proliferation.

The system is also designed to hold a light pipe, which may be helpful for illuminating the peripheral retina during cases of retinal detachment repair. The navigation system shows the observation area of the endoscope, making it easy to use.

Further clinical utility is under investigation, including automatic recognition of retinal lesions and instrument tracking.¹⁴ Furthermore, our team is developing an endoscope with a 10 mm or 15 mm insertion section (current models have a 30 mm insertion section) to reduce the risk of the endoscope coming into contact with the retina.

There are some limitations to this system. First, because many vitrectomies do not require observation or treatment of the peripheral retina, there are only a limited number of cases that require the use of an endoscope. Second, this

robot does not have insurance coverage, which places a financial burden on the medical practice. Third, it may be difficult to add new equipment to a crowded OR. Finally, it comes with a learning curve and would require a licensing system similar to other surgical tools.

THE FUTURE

Although this robotic system is helpful, many needs still exist within vitreoretinal surgery; surgeons continue to struggle with recurrent macular holes, proliferative diabetic retinopathy, and proliferative vitreoretinopathy, to name a few. The advent of intraoperative OCT and 3D heads-up surgery has enabled more precise surgical intervention, with the hopes of improving surgical outcomes. In the same way, robotic surgery may enable new vitreoretinal techniques to further improve outcomes and preserve patients' vision. ■

1. D'Ettorre C, Mariani A, Stilli A, et al. Accelerating surgical robotics research: a review of 10 years with the Da Vinci Research Kit. *IEEE Robotics Automat Mag*. 2021;28(4):56-78.
2. Surgical robots market by application (orthopaedics, neurology, urology, gynaecology, general surgery, others), end-user (hospitals, ambulatory surgical centres, others), by geography, segment revenue estimation, forecast, 2021-2030. Market Research Report. Published May 2022. Accessed October 3, 2023. bit.ly/3FISp9h
3. Kwartowitz DM, Herrell SD, Galloway RL. Toward image-guided robotic surgery: determining intrinsic accuracy of the da Vinci robot. *Internat J Comp Assist Radiol Surg*. 2006;1:157-165.
4. Charles S, Das H, Ohm T, et al. Dexterity-enhanced telerobotic microsurgery. Presented at: the International Conference on Advanced Robotics Proceedings; 1997.
5. Pandey SK, Sharma V. Robotics and ophthalmology: Are we there yet? *Indian J Ophthalmol*. 2019;67(7):988-994.
6. Ueta T, Yamaguchi Y, Shirakawa Y, et al. Robot-assisted vitreoretinal surgery: development of a prototype and feasibility studies in an animal model. *Ophthalmology*. 2009;116(6):1538-1543, 1543.e1-2.
7. Edwards TL, Xue K, Meenink HCM, et al. First-in-human study of the safety and viability of intraocular robotic surgery. *Not Biomed Eng*. 2018;2:649-656.
8. Cehajic-Kapetanovic J, Xue K, Edwards TL, et al. First-in-human robot-assisted subretinal drug delivery under local anesthesia. *Am J Ophthalmol*. 2022;237:104-113.
9. Ahronovich EZ, Simaan N, Joos KM. A review of robotic and OCT-aided systems for vitreoretinal surgery. *Adv Ther*. 2021;38(5):2114-2129.
10. Roizenblatt M, Gruenmacher AT, Belfort Junior R, Maia M, Gehlbach PL. Robot-assisted tremor control for performance enhancement of retinal microsurgery. *Br J Ophthalmol*. 2019;103(8):1195-1200.
11. Yamamoto S, Kuroki Y, Ide T, et al. Customization of a passive surgical support robot to specifications for ophthalmic surgery and preliminary evaluation [published online ahead of print August 10, 2023]. *Jpn J Ophthalmol*.
12. Wong SC, Lee TC, Heier JS, Ho AC. Endoscopic vitrectomy. *Curr Opin Ophthalmol*. 2014;25(3):195-206.
13. Zhou D, Kimura S, Takeyama H, et al. Eye explorer: A robotic endoscope holder for eye surgery. *Int J Med Robot*. 2021;17(1):1-13.
14. Zhou D, Takeyama H, Nakao S, Sonoda KH, Tadano K. Real-time fundus reconstruction and intraocular mapping using an ophthalmic endoscope. *Int J Med Robot*. 2023;19(3):e2496.

SHINTARO NAKAO, MD, PHD

- Professor and Chair, Department of Ophthalmology, Juntendo University School of Medicine, Tokyo, Japan
- s.nakao.dk@juntendo.ac.jp
- Financial disclosure: Consultant (Nipro); Patent (Riverfield); Speaker (Machida)

KOTARO TADANO, PHD

- Associate Professor, Institute of Innovation Research, Tokyo Institute of Technology, Yokohama-shi, Japan
- tadano.k.aa@m.titech.ac.jp
- Financial disclosure: Shareholder/Board Member (Riverfield)

KOH-HEI SONODA, MD, PHD

- Professor and Chair, Department of Ophthalmology, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan
- k.sonoda.a74@m.kyushu-u.ac.jp
- Financial disclosure: Consultant (Nipro); Patent (Riverfield); Speaker (Machida)