Review Article

Robotics and ophthalmology: Are we there yet?

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Ophthalmology is a field that is now seeing the integration of robotics in its surgical procedures and interventions. Assistance facilitated by robots offers substantial improvements in terms of movement control, tremor cancellation, enhanced visualization, and distance sensing. Robotic technology has only recently been integrated into ophthalmology; hence, the progression is only in its initial stages. Robotic technologies such as da Vinci Surgical System are integrated into the field of ophthalmology and are assisting surgeons in complex eye surgeries. Ophthalmic surgeries require high accuracy and precision to execute tissue manipulation, and some complex ocular surgery may take few hours to complete the procedures that may predispose high-volume ophthalmic surgeons to work-related musculoskeletal disorders. A complete paradigm shift has been achieved in this particular field through the integration of advanced robotic technology, resulting in easier and more efficient procedures. Where robotic technology assists the surgeons and improves the overall quality of care, it also projects several challenges including limited availability, training, and the high cost of the robotic system. Although considerable studies and trials have been conducted for various robotic systems, only a few of them have made it to the commercial stage and ophthalmology, on its own, has a long way to go in robotics technology.

Key words: da Vinci robotic system, robotics in ophthalmology, intraocular robotic interventional surgical system, telerobotic technology, femtosecond laser cataract devices, robot assisted vitreoretinal surgery, ZEUS Robotic Surgical System (ZRSS), multi-arm hybrid robotic system

Access this article online
Website: www.ijo.in
DOI: 10.4103/ijo.IJO_1131_18
Quick Response Code:

Recent advertisement of femtosecond laser system as “robotic cataract surgery” generated interest among ophthalmologists and patients. Robotics have indeed revolutionized various surgical specialties, including orthopedics, gynecology, urology, and laparoscopic surgery.[1] Robot-assisted surgery provides plenty of improvement over unassisted human hands such as high precision, improved dexterity in small spaces, more range of motion, and tremor filtration.[1,2] Innovations have also been made in the field of ophthalmology and the robotic surgery integration has been the most major recent advancement.

Numerous prototypes and designs have been introduced in recent years to utilize in ophthalmic surgery as well.[3] Surgical robots in ophthalmology have the ability to advance the treatments, decrease the rates of complications, and also offer the potential of treating conditions that remain incurable even today.

Majority of the robotic surgical systems in this field in the past have mostly focused on the singular tasks, typically the ones that were delicate. Although there is still ongoing research in this area, there has been an increasing interest in developing devices which can perform complete surgical procedures. The main goal for these surgeries would be to include more efficiency and speed without losing the ability of increased precision.[4] Another requirement to meet this goal is to add the ability to switch instruments mid-surgery, manipulation of the surgical instrument simultaneously, and an adequate range of motion.

Robotics in Medicine-A Historical Account

Robotics is not a new concept in the medical field. Medical professionals have been using robot-based applications in medicine to assist them in various ways. As the meaning denotes, robots are essentially meant to provide labor to make the work easier for humans. Over the past 20 years, robotics has made a place in various subspecialties of the medical world.

First developed by the Mechatronics in Medicine Laboratory, Imperial College, London, United Kingdom, it has been almost 30 years since robots were devloped for of physician's assistance in the surgical rooms. The first robot, *Probot*, was designed primarily to aid the medical team in the transurethral resection of the prostate in 1991.[5]

With technological progression, the robotics in the surgical field advanced as well and the world witnessed integration of robotics such as Zeus and da Vinci systems in the medical industry. These systems have been incorporated in the surgical procedures at a remarkable speed. Within the span of 10 years,

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Manuscript received: 06.07.18; Revision accepted: 13.02.19

Cite this article as: Pandey SK, Sharma V. Robotics and ophthalmology: Are we there yet? Indian J Ophthalmol 2019;67:988-94.

the medical industry transformed as healthcare organizations started to utilize these systems in the clinical practice.

When taken in literal terms, the robot means a machine that is designed to execute unintelligible and repetitive tasks. However, today they are used for performing tasks that require extreme precision, specification, and entail certain risks and danger. The robotic technology presently is able to perform research and tasks which cannot be possibly done using human workforce.[6]

Despite the effectiveness of robotics in the field of surgery and medicine, a slow progress has been witnessed in the overall integration of technology in the health industry. They have taken a slow route entering into the field but are gaining steady advancement with the passage of time. The telesurgical machines are used for the transcontinental robot-assisted cholecystectomy for quite some time now. The newer technology like voice-activated robotic arms has joined the industry recently.

Introduction of robotic technology in the medical field has instigated a complete paradigm shift. It has made the procedures easier and more efficient and has improvised the overall quality of care.[6-8] The subsequent section of the review article sheds light on how the ophthalmologists can benefit from this particular advancement.

Robotics in Ophthalmology

Figs. 1-3 illustrate some of the robotics model used in ophthalmic surgery. Although it has become vital for all levels and all kinds of surgeries to be highly accurate and precise when it comes to tissue manipulation, ophthalmologic surgeries are unique for their limited surgical area and minuscule tissue structure. The delicate ocular surgical procedures are subjected to several limitations. Factors such as hand tremors and the degree of control over the sensitive tissue can make a huge difference.

Robotic surgery in the medical field is generally implemented in the context where the surgeon is able to operate using smart instruments that have a superior level of functions. Mainstream clinical care has been able to improvise magnificently because of the assistance offered through surgical robots. This technology has sufficiently offered the professionals abilities to have three-dimensional views, superior instrument maneuverability, increased magnification, and diminished error possibility.

As a matter of fact, ophthalmology is a medical specialty that requires stabilized hand movement, adequate lighting, and a clear and unobstructed view. Robotic surgery is clearly suitable for these requirements. It has curtailed the possibilities of collateral tissue damage and threats directed towards visualization. Technically, surgeries in ophthalmology are complicated and unlike other surgical procedures, ophthalmologists are able to work on the surgical site and ocular structures directly. This provides them greater visibility but also enhances the risks involved as the sensitive and delicate ocular tissue (e.g. retina) is prone to get damaged even on the slightest error from the surgeon's end. This challenge has been significantly addressed through the robotics technology. According to the study of Tsirbas *et al*., the robotic instrumentation can offer the performing surgeons ability to execute a short learning curve and improve their overall surgical speed.[8]

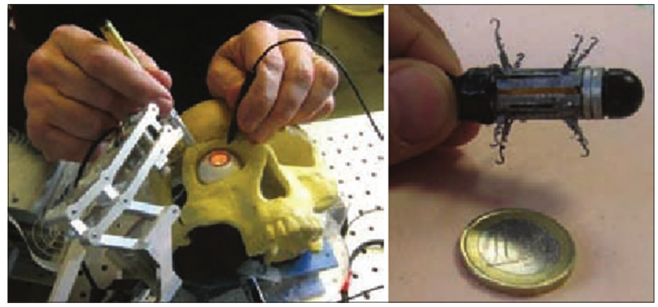

Figure 1: A Steady-hand Eye Robot Developed in Johns Hopkins University for Retinal Microsurgery. (Figure courtesy- Johns Hopkins University)

Figure 2: Da Vinci Surgical System. (Figure courtesy- Intuitive Surgical, USA)

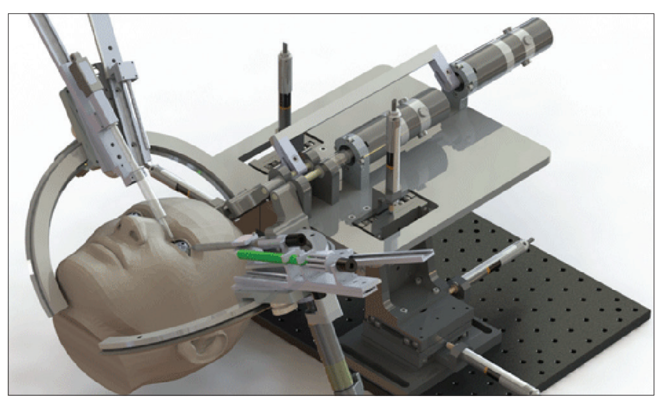

Figure 3: Intraocular Robotic Interventional Surgical System. (Figure courtesy- Mechatronics)

As a matter of fact, the robotic technology is able to provide the precision of 1 mm currently. This is only going to develop further as the technology is advancing in the field of ophthalmology. Robotic surgery in the ophthalmologic industry, although currently in very early phase, possesses significant scope. It can sufficiently fulfill the gap where there is a lack of professional assistance. Theoretically, developing countries, for instance, can benefit from this precise technological opportunity if these devices are produced by local manufacturers and are made accessible to the practitioners. These robotic devices can facilitate the surgeries that are otherwise unavailable in the territory. India can be taken as an example. There are substantial implications in the implementation of the robotics technology in ophthalmology such as direct robotic costs, availability and maintenance of the devices, and staff training. However, if the technology is successfully implemented, it can bring productive outcomes in the field.

There are several robotic technologies that have been successfully integrated into the ophthalmic surgical procedures. The following sections offer an overview of the da Vinci System that is the most commonly used robot in the field of ophthalmology.

The da Vinci Surgical System

The da Vinci system is the current standard robotic surgical system used in the field of ophthalmology. Developed by the Intuitive Surgical, USA, it is a telemanipulation robot that has been utilized for performing pterygium surgery in human eyes and has been successful in *ex vivo* corneal surgery.

This system, essentially, comprises of two primary components: a control console and the robotic apparatus. The control console is for the surgeon to manipulate the robotic arms using the remote. The robotic apparatus comprises of three, sometimes four, arms that serve the purpose of holding a dual channel endoscope. The console offers an ocular viewfinder that offers a stereoscopic view of the operative field from the endoscope. The da Vinci system allows the surgeon to manipulate the controls of the console using their fingers, wrists, hands, and arms. These movements are then transferred to the robotic arms once they are filtered and scaled by the computer processor. No significant delay is incurred between the movements of the surgeon and that of the robotic arms and system.[9]

The movements of the surgeon are almost mirrored by the system, except that the tremors and minor movements are filtered by the processor. The system is designed in a manner that it allows the surgeon to insert, extract, roll, yaw, and grip the tools of the robot. Three arms of system carry surgical instruments, and the fourth arm, which is only recently added, manipulates the digital stereoscopic camera to visualize the field or area under surgery. Each of the arms has several joints, allowing the system to have a three-dimensional movement of the surgical instruments and optics. The tools have technology that offers movement up to 360°. This is called EndoWrist technology.

Three arms designated to operate surgical tools can handle dissecting forceps, scissors, scalpel, spreaders, and other similar tools. The stereoscopic camera in the fourth arm comprises of a lens and dual stereoscopic cameras. The lens comprises of a video imaging column and two light sources to illuminate the field of surgery. The dual stereoscopic cameras are for the three-dimensional vision having progressive magnification, offering a magnified image up to 12-15 times.

The console in the da Vinci system has an optical viewing system, known as the stereo viewer which offers a three-dimensional view of the operating field and showcases the messages and icons from the system, indicating the status of the robot in real time. There are two telemanipulation handles that allow remote manipulation of the four articulated robotic arms. The da Vinci SI, the updated version of the system, offers two consoles, enabling two surgeons to operate simultaneously. However, out of the two operators, one is the primary robotic surgeon and the other a surgical assistant. Contrary to the other newer versions, da Vinci SI has three robotic arms instead of four and they can be utilized by two operators at the same time.[10]

da Vinci System in Ophthalmic Surgery

The da Vinci system can offer tremendous benefits to the ocular surgical procedures, making them more effective and convenient to proceed. The most significant property of the robotic system is its optical magnification. The stereoscopic camera in the system offers optical and digital magnification of the field of surgery, enabling the surgeon to have a clear and unobstructed view of the specific area.[11,12]

Secondly, the ability of the system processor to control and filter the tremors in the surgeon's movements results in limiting the human error and improving the quality of surgical movements. The joints in the robotic arms enable a 360º movement which ultimately offers optimal positioning and accuracy during the surgery. The da Vinci robot surgical system is designed in a manner that it simplifies the motion. The console for the surgeons ensures better comfort during microsurgery. To operate with minimal incisions and for conducting minimally invasive surgeries, the da Vinci system offers great support through offering a magnified vision, adequate illumination, and fine surgical movements.[12]

The da Vinci system is the only surgical telemanipulator that is available in the market and is currently being introduced in the field of ophthalmology for anterior and posterior segment procedures. It can be effectively used in the procedures of corneal laceration repair, pars plana vitrectomy, intraocular foreign body removal, anterior capsulorhexis, penetrating keratoplasty, and pterygium surgery.[13-15]

Limitations of the da Vinci Robotic System Design

The design of the da Vinci surgical system in the field of ophthalmology is not completely sans challenges. There are some limitations in the design that obscure its optimal functioning and application in the practical world. The first limitation is the presence of high remote center of motion (RCM) in the robot, placed right above the wrist and at a long distance from the tip of the instrument. This location of the RCM makes the intraocular movements less controllable and promotes unnecessary tension of the surface of the external eye. This demands the surgeon to utilize another RCM in the procedure during the ocular penetration site.[14]

This system requires the surgeon to move the robotic arms rather vigilantly to ensure the right positioning and movement of the RCM. These motions, as a matter of fact, are not as sensitive as the human wrists and cannot mirror the exact movements of the surgeon's arms. As a result, the range of motion gets limited. This, subsequently, results in creating challenges in the complex ocular procedures such as creating round, curvilinear capsulorhexis that is mandatory for cataract surgeries.

The second limitation in the process of using the da Vinci surgical robots in ophthalmologic procedure is the achievement of intraoperative visualization. The robot entails a video capture system that is designed essentially for the endoscopic use and cannot offer an optimal and detailed image like that of an operating microscope. Considering that technology is still in its initial stages, it is likely to progress and address these limitations with advancement.[15]

Application of Robotics in the Ophthalmic Surgery

The robots created for operating on the eyes must meet specific basic requirements. There are three designs that are being developed currently for telemanipulators utilizing virtual or fixed remote center of motion, comanipulation devices, and smart surgical tools such as a steady hand.[16] There are several potential applications of robotic technology in the field of ophthalmology. Some of them are discussed underneath.

Corneal laceration repair

According to the study of Tsirbas *et al*.,[8] the da Vinci surgical system has been successfully used in the repair of the corneal lacerations in harvested porcine eyes. The research study compared the time taken to complete the surgery through human performance and the robotic arm performance. In the system-performed surgery, a videoscope and two 360º rotating, 8-mm instruments with three robotic arms were positioned over the eye. The surgery was performed using a robotic system console and was successfully executed with the advanced visualization offered to facilitate the process and control the delicate placement of the corneal sutures.

Retinal vascular microsurgery

The study of Jensen *et al*. presents the application of the da Vinci surgical system to perform retinal microsurgery.[17] In their research, they used a six degree of freedom manipulator that required a hand-held trackball to operate. A computer controller was used to interpret the input of the trackball and the manipulator was moved according to a pre-programmed algorithm. The researchers claim that the device can be used in microsurgery and limit the aspects of tremor and fatigue. The device, however, has its limitations of size and operational features.

Vitreoretinal surgery

The study conducted by Dogangil *et al*. refers to the usage of miniature autonomous robots or microrobots.[18] These devices are so tiny that they can fit into the barrel of a syringe and can execute movements like that of a submarine. Alongside, the researchers are working on developing a three-dimensional visual serving approach that has the capability to carry microneedles and chemical sensors which can help in the process of surgery and diagnosis. The objective of the research is to develop controlled magnetic fields that can steer the microrobot, whereas an active microscope can offer a real-time, three-dimensional feedback. This can allow drug delivery in the field of vitreo-retinal surgery using wireless magnetic microrobots.[18]

Telerobotic Technology

The article of Volpe elaborates the commercial use of the robot-assisted microsurgery system.[19] The system utilizes the telerobotic technology of NASA to carry out a precision cable-driven system that offers efficient functioning. It scales down the human input motions, filters tremors to improve the accuracy and precision, and offers constrained motion of the instrument in the eye to curtail any surgical mishaps and detrimental impacts.[19]

Utilizing telerobotic systems and programming them to utilize motion scaling, stepwise nudging, and z bounds can enhance both safety and speed when moving towards the target point.[20] Progressively increased autonomous and automated surgeries are most likely the path forward and with the rapid research and advancements underway currently, this can be possible in near future and can result in further revolutionizing the field of ophthalmology. Application of robotics in ophthalmology is summarized in Table 1. Table 2 summarizes the studies published on robotics and ophthalmology.

The Scope of Robotics in Ophthalmology

In ophthalmology, robotics is in its initial stage but with increasing development and research in this area, it is expected to reach a stage where it can be introduced in the normal ophthalmic practices. It can be rational to presume that there are plenty of opportunities for robotics ophthalmic surgeries, especially in intervention performance that is only rendered possible with robotic systems, or might atleast greatly simplify the existing approaches.[21] Procedures such as intravascular drug delivery and retinal vessel cannulation may become feasible since robotic microsurgical manipulations would be safer with reduced iatrogenic complications. Additionally, advanced imaging integration with robotic systems might also allow motion guidance or total surgical procedures automation.

There are numerous more potential pathways of bringing robotics in the field of ophthalmology. Up until now, all the surgical systems enhance the time of surgery. However, there is a need to emphasize cost and efficiency as well. The setup time can be drastically reduced by utilizing a hybrid system implemented on current surgical tables.[22]

Although robotic technology in ophthalmology is still in its startup stages, the trend is expected to follow through consistently and tremendous advancement is anticipated in the field in the coming times. To gain a better understanding of how well the robotics technology is developing in the field, the following section offers a brief overview of the potential benefits and challenges.

Potential Benefits of Robotics in Ophthalmology

One of the reasons why robotics technology in ophthalmology is highly anticipated is the meticulousness achieved through

Table 1: Application of Robotics in Ophthalmology

Robotics in Ophthalmology	Place and Year of Development	Functions
1. Stereotaxical Micro-telemanipulator for Ocular Surgery	France, 1980s	Allows 4 degrees of rotation with translation to facilitate precise movements.
2. Prototype robotic system based on the S.M.O.S. platform	Japan, 1989	Assists in vitreoretinal surgery and increased accuracy. The prototype eliminates the interoperator variability to enhance precision.
3. Steady hand manipulator for retinal microsurgery	John Hopkins University, Baltimore, Maryland, USA, 1999	Reduces tremors, and minimizes undesirable eye wall tension.
4. Multi-arm hybrid robotic system	Columbia University, USA, 2009	Offers skillful manipulation of eye.
5. Da Vinci Surgical System	The United States, approved in 2000 by FDA	Used in performing suture repair of a corneal laceration, executing complete continuous capsulorhexis on the anterior lens capsule, and to perform 3-port 25-gauge pars plana vitrectomy.
6. Hexapod Surgical System	France, 2011	Mounted to the da Vinci Macro Robot, this system offers a remote center of motion at the site of ocular penetration.
7. Micro Hand using the micro electromechanical systems technology, (MEMS)	USA, 2010	Offers manipulation of fresh retinal tissue and can maneuver caliper weights. It is designed in the same manner as a human hand.
8. Intraocular Robotic Interventional Surgical System	Mechatronics and Control Laboratory and Stein Eye Institute, USA 2011	It is designed to facilitate telesurgery using a stereoscopic visualization system, joystick controls, and custom designed arms. This system is equipped with tremor filtration and performs scaled motion.
9. Femtosecond Laser Devices	The United States, approved by FDA in 2001	Facilitates cataract surgery and can be used in wound construction, capsulorhexis creation, and nucleus breakdown during the cataract surgery.

it. The challenges formerly experienced in form of movement stability are now addressed through the robotics. The surgeons are able to scale both movements and speed at the same time. This has promoted their efficiency in performing delicate tasks.[23,24]

Robotic techniques and high-precision instruments have made it achievable for the ophthalmologists to address more complex and accuracy-sensitive conditions. The robotic systems are effective for the purposes that require repetitive tasks, making the work easier for the ophthalmologist.[25]

Micro-incision cataract surgeries that were once deemed difficult to execute, they are now substantially aided with robotic technology such as Femtosecond lasers. These devices are effective in performing precise corneal incision, well-sized perfect capsulorhexis, and nuclear fragmentation and help to improve the outcome of refractive cataract surgery. Remaining steps of phacoemulsification procedures can be performed by the ophthalmic surgeons. In the future, the robotic system can take over the tasks that involve repetitive motions, providing the depth and strength that is ideal for the task to be carried out.[26]

To achieve optimum results, it is important that the surgeon knows well how to operate the robotic system. With this challenge, there are several opportunities rising as well. According to the latest trend, the surgeons are now trained on simulators. The information and steps that are preprogrammed into the simulators and the robot make it easier for the surgeons to execute the transition from one step to another. This makes the work easier for surgeons to perform and in less time.[27]

While performing invasive surgeries, the surgeons have to be careful about their posture and movements as any unwatchful movement can cause substantial damage to the tissue. This has limited the freedom in the movement for the surgeons and has led them to suffer from occupational musculoskeletal disorders. Therefore, it is not just the patient's safety and treatment that demands advancement in the surgical procedures, but the well-being of the surgeons as well.[28]

Robotic techniques cater to both the demands sufficiently. Where they have improved the quality of treatment for the patients with marginalized risks, they have also granted considerable relaxation and comfort to surgeons. These techniques are able to reduce the physical stress endured during the surgery.

It is difficult to predict the exact scope of robotics in ophthalmology, but it can be effectively deduced by comparing the results of robot-performed and human-performed surgeries. There are ongoing research trials to determine how surgical robots can be used in improving the ophthalmological productivity and which procedures can be accelerated without causing any negative impact.

Challenges: Robotics in Ophthalmology

Robotic-assisted advancement is not sans challenges. There are issues which need to be carefully considered so that they are effectively resolved. Ophthalmological procedures need logical processing for effective execution aside from accuracy. For an ophthalmic surgeon, who is taking the assistance of a robotic system, he/she must be able to carry out the procedure in a sequence of steps that are logical.

Table 2: Studies Published on Robotics and Ophthalmology

Name of Author/ Year	Type of Surgery	Robotics & Ophthalmology	Comments
1. Tsirbas, A., Mango, C. and Dutson, E., 2007	Bimanual, three-dimensional robotic surgery. Ocular microsurgery was performed using da Vinci Surgical Robot.	Ocular microsurgery was performed using a da Vinci surgical robot. Repair of corneal laceration done in a porcine model. Excellent visualization was obtained during the surgery and the sutures were placed delicately at the corneal level with controlled movements.	Robotic ocular microsurgery has proven to be successful. Moreover, it can make the procedure more time-efficient.
2. Smet, MD., Naus, GJL., Faridpooya, K., and Mura, M., 2018	Presents overview of intraocular surgery, *ex vivo* corneal surgery, and semiautonomous surgery	Reviewed three robotics used in ophthalmic procedures: steady hand manipulator for retinal microsurgery, Preceyes surgical system for intraocular surgery, and da Vinci Surgical Robot for ex-vivo corneal surgery.	Several eye-specific systems have proven to be successful in different ocular surgeries, but only a few of these robotic systems have been able to make it to the commercial platform. Despite the development, robotic systems will take time to get incorporated in the surgical procedures.
3. Hubschman, JP., Tsirbas, A., and Schwartz, SD., 2008	Robotic external ocular surgery was performed using robotic arms.	Robotic arms were used to carry out a 25 gauge robotic vitrectomy. Robotic forceps were used to grasp and subsequently remove the foreign body from the anterior chamber. A 360 degree capsulorhexis was achieved through the movement of the robotic arms.	Robotic arms are not much feasible to use in ocular surgery. The visualization gets hindered and continuously requires realignment. Conversely, robotic forceps offer more ease in manipulation and control of the instruments. However, the procedure can be improved substantially through miniaturization.
4. Noda Y, Ida Y, and Tanaka S., *et al.*, 2013	Application of robotic instruments and system for vitreoretinal surgery	The capability of robotics application to target the fundus was analyzed in comparison to the manual procedure and performance.	Robotic assistance in approaching the target on the fundus, and to stabilize the manipulator tip above the fundus ensures more accuracy and improves the contact with the target. This has proven to be beneficial for both experienced and inexperienced hands.
5. Roizenblatt M, Edwards TL, and Gehlbach PL., 2018	Robot-assisted vitreoretinal surgery	Robotic systems considerably suppress tremor during the vitreoretinal surgery and improves the coordination between the surgeon and the robot. Vitrectomy is executed with more precision by robotics when it is combined with intravenous thrombolysis.	Improved control, dexterity, diminished tremors, and micron-scale distance sensing has been achieved in vitreoretinal surgery through robotics. However, there are substantial challenges in implementation including costs, clinical risks and complications.
6. Bourla DH, Hubschman JP, Culjat M, *et al.*, 2008	Intraocular Robot surgery using da Vinci Surgical System.	The da Vinci Surgical System was utilized in performing different surgical procedures including 25-gauge pars plana vitrectomy, intraocular foreign body removal, and anterior capsulorhexis. The aim of the study was to assess the robot's ability to offer control to the surgeon, improve dexterity and maneuverability, and enhance visualization.	The da Vinci Surgical System successfully offered complete range of movement. Steady motion with optimum dexterity was achieved. To retain excellent visualization, realignment was required. This highlights the shortcomings of da Vinci Surgical System in ocular surgeries.

The devices utilized must be innately perceptive. For an optimally functioning robot, it is important that it functions as a highly skilled and proficient human being.[29] If the device deviates from the logical progression, it will not achieve the purpose it is designed for.

If the robotic surgical device, da Vinci, is taken into consideration, it does allow the surgeon to achieve a magnified view of the eye and perform corneal incision but its frame rigidity does not reciprocate the flexible movements like that of a surgeon.[30]

We can regard da Vinci as one of the indirect devices used in ophthalmology and, ophthalmology, on its own, has a long way to go in robotics technology. The study of Bourla, *et al.*, however, advocates the suitability of the da Vinci robotic system for ocular surgeries.[31] There are several issues highlighted in terms of levels of stress at the entry points and in relation to the visualization of the surgical field. These issues denote that the da Vinci robotic system is not completely appropriate as yet for ocular surgeries.

With the current and existing progression of surgical robot systems in ophthalmology, it has become difficult to predict how robotic technology is going to proceed. The future is mostly dependent on the clinical trial data that is to be achieved through ongoing pilot studies. Once the relevant data is achieved, more in-depth analysis can be conducted for the scope of robotics in ophthalmology. Several obstacles remain before robotic surgery will become popular in ophthalmology. A high cost, steep learning curve, and patient trust present other challenges in robotics in ophthalmology. At present, considerable studies and trials have been conducted for various robotic systems, only a few of them have made it to the commercial stage and ophthalmology, on its own, has a long way to go in robotics technology.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Kumar R, Hemal AK. Emerging role of robotics in urology. J Min Access Surg 2005;1:202-10.
2. Dasgupta P, Challacombe B, Murphy D, Khan MS. Coming full circle in robotic urology. BJU Int 2006;98:4-5.
3. Fine HF, Wei W, Roger Goldman E, Simaan N. Robot-assisted ophthalmic surgery. Can J Ophthalmol 2010;45:581-4.
4. Ruurda JP, Broeders IAMJ, Simmermacher RPM, Borel Rinkes IH, Van Vroonhoven TJ. Feasibility of robot-assisted laparoscopic surgery: An evaluation of 35 robot-assisted laparoscopic cholecystectomies. Surg Laparosc Endosc Percutan Tech 2002;12:41-5.
5. Cleary K, Nguyen C. State of the art in surgical robotics: Clinical applications and technology challenges. Comput Aided Surg 2001;6:312-28.
6. Lanfranco A R, Castellanos AE, Desai JP, Meyers WC. Robotic surgery: A current perspective. Ann Surg 2004;239:14-21.
7. Jones SB, Jones DB. Surgical aspects and future developments of laparoscopy. Anesthesiol Clin North America 2001;19:107-24.
8. Tsirbas A, Mango C, Dutson E. Robotic ocular surgery. Br J Ophthalmol 2007;91:18-21.
9. Rahimy E, Wilson J, Tsao TC, Schwartz S, Hubschman JP. Robot-assisted intraocular surgery: Development of the IRISS and feasibility studies in an animal model. Eye 2013;27:972-8.
10. Liverneaux PA, Hendriks S, Selber JC, Parekattil SJ. Robotically assisted microsurgery: Development of basic skills course. Arch Plast Surg 2013;40:320-6.
11. Bourcier T, Nardin M, Sauer A, Gaucher D, Speeg C, Mutter D, *et al*. Robot-assisted pterygium surgery: Feasibility study in a nonliving porcine model. Transl Vis Sci Technol 2015;4:9.
12. Bourges JL, Hubschman JP, Wilson J, Prince S, Tsao TC, Schwartz S. Assessment of a hexapod surgical system for robotic micro-macro manipulations in ocular surgery. Ophthalmic Res 2011;46:25-30.
13. Bourges JL, Hubschman JP, Burt B, Culjat M, Schwartz SD. Robotic microsurgery: Corneal transplantation. Br J Ophthalmol 2009;93:1672-5.
14. Mitchell B, Koo J, Iordachita I, Kazanzides P, Kapoor A, Handa J, *et al*. Development and application of a new steady-hand manipulator for retinal surgery. InRobotics and Automation, 2007 IEEE International Conference on 2007 Apr 10. IEEE, p. 623-9.
15. Taylor RH, Menciassi A, Fichtinger G, Fiorini P, Dario P. Medical robotics and computer-integrated surgery. In: Springer Handbook of Robotics. Cham.: Springer; 2016. p. 1657-84.
16. Smet MD, Naus GJL, Faridpooya, K, Mura M. Robotic-assisted surgery in ophthalmology. Curr Opin Ophthalmol 2018;29:248-53.
17. Jensen PS, Grace KW, Attariwala R, Colgate JE, Glucksberg MR. Toward robot-assisted vascular microsurgery in the retina. Graefes Arch Clin Exp Ophthalmol 1997;235:696-701.
18. Dogangil G, Ergeneman O, Abbott JJ, Pané S, Hall H, Muntwyler S, *et al*. Toward targeted retinal drug delivery with wireless magnetic microrobots. In: Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on 2008 Sep 22. IEEE, p. 1921-6.
19. Volpe R. The RAMS arms. Available from: http://www-robotics.jpl.nasa.gov/systems/. Retrieved on 2018 Oct 22.
20. Harris JM, Nefs HT, Grafton CE. Binocular vision and motion-in-depth. Spatial Vis 2008;21:531-47.
21. Marescaux J, Leroy J, Rubino F, Smith M, Vix M, Simone M, *et al*. Transcontinental robot-assisted remote telesurgery: Feasibility and potential applications. Ann Surg 2002;235:487-92.
22. Hubschman JP, Tsirbas A, Schwartz SD. Robotic surgery in ophthalmology. Retina Today 2008;81-4.
23. Spitznas M. Motorized teleguided stereotactic micromanipulator for vitreous microsurgery, Arch Ophthalmol 1983;101:623-30.
24. Noda Y, Ida Y, Tanaka S, Toyama T, Roggia MF, Tamaki Y, *et al*. Impact of robotic assistance on precision of vitreoretinal surgical procedures. PloS One 2013;8:e54116.
25. Roizenblatt M, Edwards TL, Gehlbach PL. Robot-assisted vitreoretinal surgery: Current perspectives. Robot Surg 2018;5:1-11.
26. Nuzzi R, Brusasco L. State of the art of robotic surgery related to vision: Brain and eye applications of newly available devices. Eye Brain 2018;10:13-24.
27. Pitcher JD, Wilson JT, Tsao TC, Schwartz SD, Hubschman JP. Robotic eye surgery: Past, present, and future. J Comput Sci Syst Biol 2012;S3:001. doi: 10.4172/jcsb.S3-001.
28. Grozdanovic D, Grozdanovic M. Research on key indicators in modern surgical practice assessment: Ergonomic approach. Surg Innov 2018;25:323-32.
29. Asimov I, Robot I. Robot series. Available from: https://en.wikipedia.org/wiki/Three_Laws_of_Robotics.
30. Takács A, Nagy DÁ, Rudas I, Haidegger T. Origins of surgical robotics: From space to the operating room. Acta Polytech Hung 2016;13:13-30.
31. Bourla DH, Hubschman JP, Culjat M, Tsirbas A, Gupta A, Schwartz SD. Feasibility study of intraocular robotic surgery with the da Vinci surgical system. Retina 2008;28:154-8.