LABORATORY SCIENCE

# Robot-assisted simulated cataract surgery

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**Purpose:** To evaluate the feasibility of robot-assisted simulated cataract surgery.

**Setting:** Institut de Recherche Contre les Cancers de l'Appareil Digestif, European Institute of Telesurgery, and Strasbourg University Hospital, Strasbourg, France.

**Design:** Experimental study.

**Methods:** Cataract surgeries were performed on a Kitaro cataract wet-lab training system simultaneously using the Da Vinci Xi robotic surgical system and the Whitestar Signature phacoemulsification system. For each procedure, the duration and successful completion of the surgery with or without ocular complications were assessed.

**Results:** Procedures were successfully performed on 25 lens nuclei. The feasibility of robot-assisted simulated cataract surgery was confirmed. The robotic surgical system provided the intraocular dexterity and operative field visualization necessary to perform the main steps of the phacoemulsification procedure; that is, corneal incisions, capsulorhexis, grooving, cracking, quadrant removal, and irrigation/aspiration of the ophthalmic viscosurgical device (OVD). The intervention of a second surgeon was required for the intraocular injections of OVD, balanced salt solution, and intraocular lenses. The mean operative time was 26.44 minutes $\pm$ 5.15 (SD). All lens nuclei were removed. Inadvertent enlargement of the main corneal incision caused by the phaco handpiece was observed in 2 cases.

**Conclusion:** Experimental robot-assisted cataract surgery was technically feasible using the new robotic surgical system combined with a phacoemulsification machine.

*J Cataract Refract Surg 2017; 43:552–557* © *2017 ASCRS and ESCRS*

Online Video

Cataract surgery is the most widely performed surgical procedure in the world. Surgical techniques have changed significantly over the past 50 years to meet the growing level of expectations of surgeons and patients. Recent advances in cataract surgery include smaller incisions, more efficient phacoemulsification machines, femtosecond laser–assisted cataract surgery, and a new generation of intraocular lenses (IOLs). Visual outcomes are constantly improving in a safe, effective, predictable, and reproducible manner. Cataract surgery is the archetype of quick, standardized, low-complication surgery. As a consequence, a potential, exciting innovation in cataract surgery might be the integration of surgical robots.[1,2]

Robot-assisted surgery has expanded over the past 20 years in macrosurgical specialties (urological, general, digestive, gynecological, cardiovascular); however, microsurgical specialties, including ophthalmology, have seen little growth in the field. The main reasons for this discrepancy include that cataract surgeons work at a nearly robotic pace by routinely performing up to 20 procedures per day; the Da Vinci Robotic Surgical System (Intuitive Surgical, Inc.) and the ARES Robot Auris Surgical Endoscopy System (Auris Surgical Robotics), the only 2 surgical robots approved by the U.S. Food and Drug Administration for human surgery, are not specifically microsurgical robots; and the cost of robotic systems might be prohibitive and the learning curves for surgeons are potentially steep. There are, nonetheless, potential advantages to the use of robotics in eye surgery, including increased precision and maneuverability of movements, scalability of motion, tremor filtration, better ergonomics, task automation, and surgical training.[3–5] In addition, the use of robotics and the development of telesurgery for cataract surgery might be a good option in areas

Submitted: December 7, 2016 | Final revision submitted: February 3, 2017 | Accepted: February 20, 2017

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Richard Bastier, Laurence Brisebard, Thomas Deroyon, Janel Hooven, Julien Lacaux, Gilles Lemoine, Eric Leplat, Olivier Moucheron, Association Alsacienne d'Ophtalmologie, provided advice, proofreading, and technical support.

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0886-3350/$ - see frontmatter
http://dx.doi.org/10.1016/j.jcrs.2017.02.020

that lack ophthalmological infrastructures or surgeons.[6] As a result, robotics might improve patient care and could well become clinically relevant for cataract surgery in the future.

The Da Vinci Robotic Surgical System is the most commonly used platform in human surgery. Four models have been launched since 2001; they are the S, Si, Si HD, and Xi. The Si model has been used in experimental conditions to suture corneal lacerations in porcine eyes,[7] to perform penetrating keratoplasties in porcine and cadaver eyes,[8] and to remove foreign bodies, lens capsules (anterior capsulorhexis), and vitreous in porcine eyes.[9] We recently used the Si HD model to perform robot-assisted ocular surface surgery (amniotic membrane transplantation and pterygium surgeries) in a clinical setting.[10,11,A] The latest version, Xi, has been on the market since 2014. One of the improvements over the original system is the 8.0 mm camera, which allows better visual definition and clarity than the previous Si HD model. The camera has an autofocus system and can be attached to any of the 4 arms as needed.

This study evaluated the feasibility of robot-assisted simulated cataract surgery using the new robotic surgical system.

## MATERIALS AND METHODS

### Robot

The Da Vinci Xi surgical system consists of the following 3 components: a mobile instrument cart with 4 articulated arms, a vision cart, and a surgeon console used to control the robotic arms (Figure 1).[12] The mobile cart contains the articulated robotic arms, 3 of which carry surgical instruments and a fourth that manipulates the digital stereoscopic camera that allows the surgeon to visualize the surgical field. The camera provides 3-dimensional (3-D) vision with progressive magnification up to 15 times and can be placed on any of the arms and autofocuses. Each of the arms has multiple joints that allow 3-D movement of the surgical instruments. The surgeon's console has an optical viewing system, 2 telemanipulation handles, and 5 pedals. The optical viewing system has a 3-D high-definition view of the operating field and displays text messages and icons that reflect the status of the system in real time. The 2 telemanipulation handles allow remote manipulation of the 4 articulated robotic arms. Master–slave controls replicate the surgeon's hand motions, filtering tremor and offering the possibility of using an adjustable motion-scaling ratio. The following robotic tools were used for the surgical procedures: ProGrasp forceps, Large SutureCut needle driver (needle driver 1), and Mega SutureCut needle driver (needle driver 2) (all Intuitive Surgical, Inc.).

### Wet-Lab Phacoemulsification Procedure Model

The Kitaro wet-lab system (FCI Ophthalmics) was used to simulate cataract surgery. The artificial anterior segment includes a cornea that provides a clear view of the anterior chamber and a cataract nucleus made of clay. The artificial capsular bag is a film made of red polyester. The cataracts are placed in a reusable artificial sclera, and the wet-lab cornea is mounted on top. The cornea has red markings for the main and side-port incisions. Soft and medium nuclei densities were used for the experiments.

### Phacoemulsification Machine

The Whitestar Signature phacoemulsification system (Abbott Medical Optics, Inc.) was used. The phaco handpiece (Ellips FX) as well as the irrigation/aspiration (I/A) handpiece were attached with adhesive tape to the distal extremity of the robotic surgical system forceps (Figures 2 and 3). The setting parameters were the following: groove program, aspiration 28 cc/min, vacuum 85 mm Hg, and ultrasound (US) power 35 pps; quadrant program, aspiration 33 cc/min, vacuum 445 mm Hg, and US power if occluded 45 pps/unoccluded 15 pps; and I/A ophthalmic viscosurgical device (OVD) program, aspiration 34 cc/min and vacuum 505 mm Hg. Venturi and peristaltic modes were both used. The wireless footpedal was installed at the right side of the surgeon's console of the robotic system.

Figure 1. Remote console of the robotic surgical system. The surgeon's console is equipped with an optical viewing system, 2 telemanipulation handles, and 5 pedals. The optical viewing system, called the stereo viewer, provides a 3-D view of the operating field. The 2 handles allow remote manipulation of the articulated robotic arms. The phaco handpiece is controlled with the pedal installed next to the robot's pedals.

### Non-Robotic Instruments

Three microsurgical tools were specifically prepared for the procedures. A single-use micromanipulator (MMSU1471, Malosa Medical) was intentionally broken at the junction between the shaft and the distal extremity. A cystotome was made using a 27-gauge bent-tipped disposable needle (Becton Dickinson and Co.), and the plastic syringe-adaptor of the needle was removed. A 2.2 mm keratome (Alcon Laboratories, Inc.) was prepared by removing the metallic extremity from the plastic shaft.

### Surgical Technique

An ophthalmic surgeon (T.B.) with experience in cataract surgery and robotic microsurgery certified by the Robotic Assisted Microsurgical and Endoscopic Society performed the surgical procedures. Surgical movements were scaled to 1.5:1. The camera was installed vertically above the eye on arm 2. A superior single-plane 2.2 mm main corneal incision was created with the keratome held by needle driver 1 (arm 4) (Figure 4) (Video 1, available at http://jcrsjournal.org). The needle of the OVD syringe was introduced into the anterior chamber using needle driver 1. With the