Virtual reality training platform for flexible ureterorenoscopy interventions with a minimally invasive surgical robot

M. Peral-Boiza[1], T. Gómez-Fernández[1], P. Sánchez-González [2,3], B. Rodríguez-Vila[2,3,4], E.J. Gómez [2,3], A. Gutiérrez[1]

m.peral@alumnos.upm.es, teresa.gomezf@alumnos.upm.es, psanchez@gbt.tfo.upm.es, borja.rodriguez@universidadeuropea.es, enriquejavier.gomez@upm.es, aguti@etsit.upm.es

[1] E.T.S. Ingenieros de Telecomunicación, Universidad Politécnica de Madrid, Madrid, España

[2] Grupo de Bioingeniería y Telemedicina, E.T.S. Ingenieros de Telecomunicación, Centro de Tecnología Biomédica, Madrid, España

[3] Centro de Investigación Biomédica en Red de Bioingeniería, Biomateriales y Nanomedicina, Madrid, España

[4] Universidad Europea de Madrid, Villaviciosa de Odón, España

Abstract

The total number of ureteroscopy (URS) interventions during the past years has dramatically increased due to the ongoing technological advances and the benefits associated with these techniques. However, the current URS procedure presents some drawbacks to urologic surgeons. The LITHOS project was created with the main objective of developing a surgical robotic system for flexible ureterorenoscopic lithotripsy interventions, offering a technological solution that meets the real needs of both patients and surgeons in this type of procedures. In this paper, a virtual reality environment for flexible ureterorenoscopy interventions is presented. The proposed environment provides a suitable training platform for surgeons manipulating the surgical robotic system.

1. Introduction

Minimally invasive surgery (MIS) involves surgical procedures that aim to cause less damage to human tissue than traditional open surgical techniques. It is performed through small incisions or trocars, so its advantages over traditional open surgery are numerous: shorter recovering periods, minor postoperative complications, less scarring, shorter hospital stays, reduced pain and lower morbidity rate [1].

Moreover, MIS indications are widely expanded in many medical areas and it provides an effective and safe alternative to traditional open surgery in different types of surgical interventions [2-4]. In addition, advances in surgical instrumentation, focused on constant equipment miniaturization and refinement, have contributed to reduce tissue damage during MIS procedures.

However, MIS also presents several drawbacks. The learning curve for most surgeons is longer when compared to open surgery, and these procedures can also present longer operating time and higher equipment costs [5]. The occasional possibility of conversion to an open procedure due to intraoperative complications can occur during MIS interventions. Moreover, ergonomics problems causing physical symptoms on surgeons have been repeatedly reported [6,7].

Robotics in surgery is also becoming an expanded technology. Computer-assisted manipulation offers greater precision and can increase the surgeon dexterity during minimally invasive procedures [5]. Some of them also include haptic feedback, which intensifies enormously the immersive experience of the surgeon in the actual intervention. The feasibility of robotic-assisted minimally invasive procedures has been demonstrated in different types of interventions [8].

Currently available surgical robotic systems for minimally invasive procedures are performing interventions in different clinical areas, such as laparoscopy, catheterization and ureterorenoscopy. The Da Vinci system (Intuitive Surgical Inc, CA, USA) is composed by four computer-manipulated robotic arms to operate the patient and a surgeon console provided with stereoscopic view. It has been demonstrated to offer advantages over traditional MIS interventions [9]. The TELELAP ALF-X surgical system (SOFAR S.p.A., ALF-X Surgical Robotics Department, Milan, Italy) provides a new robotic approach to minimally invasive procedures, offering haptic feedback and 3D vision to the surgeon. It comprises a remote control unit and a patient site with manipulator arms. Its feasibility and effectiveness in different MIS procedures have been reported [10]. The RAVEN Surgical Robot (University of Washington, WA, USA) is a robotic system for MIS procedures that provides haptic interaction. It includes the patient side with two articulated manipulators, and the surgeon site composed of two control devices and video display from the operation site. It has been used in several telesurgical experiments, obtaining successful outcomes [11]. The robotic Percutaneous Access to the Kidney (PAKY) device (The Johns Hopkins Medical Institutions, MD, USA) is comprised of a radiolucent, sterilizable needle driver located at the terminal end of a robot arm. Its accuracy and feasibility when combined with a remote center of motion (RCM) device have been determined in comparison to standard manual access [12]. The magnetic navigation system Niobe (Stereotaxis, MO, USA), for catheter interventions, is based on two computercontrolled permanent magnets that are located on opposite sides of the patient, generating an external magnetic field that can be precisely manipulated [13]. The robotic catheter system Sensei X2 (Hansel Medical Inc, CA, USA) includes the Artisan Extend Control Catheter and a remote surgeon console with 3D imaging displays and a master input device. This system allows force feedback to the surgeon when performing surgical procedures. In addition, it was demonstrated that the Sensei system presents some benefits in ureterorenoscopic interventions compared to conventional procedures [14]. Finally, the Avicenna Roboflex (ELMED, Ankara, Turkey) is a robot specifically designed for flexible ureteroscopy. It is composed of the surgeon console and the manipulator of the flexible endoscope. Two joysticks and pedals, a wheel and a control monitor allow manipulating the endoscope from the remote unit. It was reported to be a suitable and safe system [15].

Although many robotic systems have been designed for MIS interventions, just a few of them are able to work on ureteroscopy. It is within this gap where the LITHOS project emerges.

2. LITHOS: robotic surgery for the treatment of renal calculi

Urinary lithiasis or urolithiasis refers to the presence of calculi in the urinary tract. This urologic disease presents a high morbidity rate in the world. One out of 11 individuals in the USA suffer from kidney stone disease at some point in their lives, being the prevalence of stones equals to 8.8% (10.6% for men and 7.1% for women) [16]. In addition, urolithiasis incidence rate in children has significantly increased in the last decades [17].

Urology recommendations state that open stone surgery has to be considered only in exceptional situations. The urolithiasis treatment recommendations included in the recent European Association of Urology (EAU) guidelines about renal and ureteral calculi have changed towards endourologic procedures, such as ureteroscopy (URS) and percutaneous nephrolithotomy (PNL), versus extracorporeal shockwave lithotripsy (SWL) [18].

The use of flexible ureteroscopy (fURS) has experienced determining improvements over the past years, including design modifications, miniaturization of the distal tip and deflection increase, along with new digital video technologies and intracorporeal lithotripsy devices [19]. These ongoing advances have led to an increase in the use of fURS and the expansion of its potential indications. It has been proved to be a safe and effective technique when performed with holmium laser lithotripsy in the treatment of urinary calculi, presenting high stone-free rate and low morbidity [20].

However, although ureteroscopy techniques offer many benefits from the patient perspective, they also present some drawbacks to urologic surgeons. This method involves serious ergonomics problems, as the surgeon has to stand during 3-4 hours interventions, holding the ureteroscope up and turning the head to look at the endoscopy and radiography screens. This position leads to muscular pains, stiff joints and even tendonitis in wrist, forearm, arm and neck. Moreover, the endourologic surgeon is exposed to important doses of ionizing radiation from X-rays, used to acquire intraoperative images.

The LITHOS project objective is the design and development of a novel surgical remotely controlled robotic system for flexible ureterorenoscopic lithotripsy interventions. The final system is based on a multifunctional collaborative robot located in the patient site for the endoscope manipulation, which is teleoperated by the surgeon from a control panel. This two site approach provides the urologic specialists with a more ergonomic workspace, remote from radiation sources.

However, prior to the development and implementation of the robotic system, a training environment must be developed, so the learning curve of the surgeons can be reduced.

3. A virtual reality training platform for flexible ureterorenoscopy

The benefits of using surgical simulation in medical training have been repeatedly reported [21]. Its advantages generally include improvements in the efficiency and skills of the surgeon, learning curve reduction, improved educational experience, reduction in costs and easier access to different types of clinical scenarios.

Simulation platforms for ureterorenoscopy training have been previously developed. URO Mentor system (Simbionix, Tel Aviv, Israel) provides a platform for the simulation of rigid and flexible cystoscopic and ureterorenoscopic procedures [22]. The Scope Trainer (Mediskills Ltd., Edinburgh, United Kingdom) allows the user to simulate standard procedures, such as ureteral or renal intracorporeal lithotripsy [23].

In order to provide an effective training environment for surgeons manipulating the LITHOS final system for the first time, a virtual reality platform of flexible ureterorenoscopy was developed.

The motions of the flexible ureteroscope (rotation, insertion and flexion) are controlled remotely from the surgeon control panel and performed in the patient site by the final actuator system. According to the feedback provided by specialists in ureterorenoscopy interventions, separation between motions in different devices allows the surgeons to have a better control of the position of the endoscope distal tip. Therefore, two 3D mice are used as remote endoscope controllers in the surgeon panel. Equivalently, two 3D mice are used to manipulate the virtual training environment (see Figure 1).

Moreover, additional features such as laser activation for lithotripsy procedure or calculi fragmentation monitoring were developed.

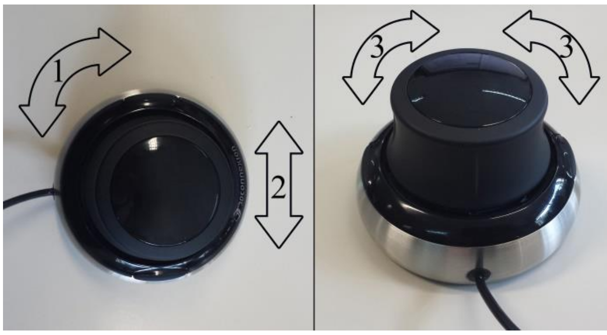

Figure 1. *3D mice used as endoscope controllers. On the left, 3D mouse for the left hand controlling rotation motion (1) and insertion motion (2). On the right, 3D mouse for the right hand responsible for flexion motion (3).*

Rotation and insertion motions of the flexible endoscope are manipulated with the left 3D mouse, whereas flexion motion is controlled with the right one. The laser activation for lithotripsy is performed by pressing both side buttons of the right 3D mouse simultaneously, in order to minimize unintentional laser shots (see Figure 1).

The virtual system was developed using the C++ simulation framework CHAI3D [24], an open-source and multiplatform environment designed to integrate tactile and visual sensations in real time.

In order to simulate the flexible endoscope, the solid model was discretized in a finite number of solid elements (spherical nodes), as depicted in Figure 2.

Figure 2. *On the left, the continuous flexible endoscope model; on the right, its discretization.*

The flexible endoscope dynamic model has been developed based on the position based approach [25] and the shape matching method [26]. Vertical distance constraints and flexion angle constraints were established between the spherical nodes, as well as collision constraints. In order to test the correct performance of the simulated flexible endoscope, different tridimensional scenarios were created. Figure 3 shows the response of the endoscope model implemented in several environments.

For creating an accurate and realistic training platform, navigation through a three dimensional ureterorenal model was implemented. The 3D model was previously acquired with a CT scan on a real urinary tract.

Figure 3. *Performance of the simulated endoscope model in three different scenarios.*

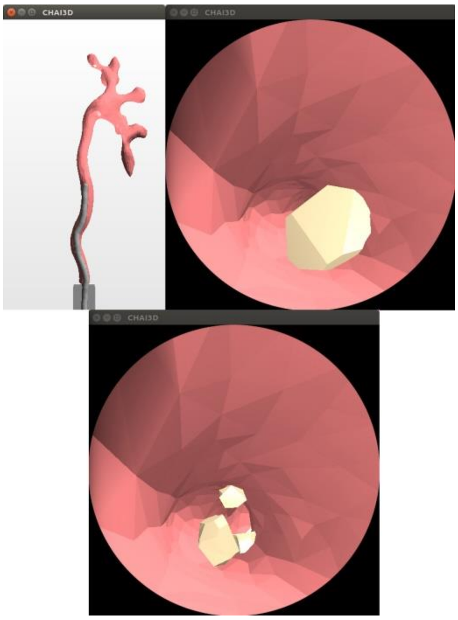

Figure 4. *Implemented virtual reality environment user interface, including endoscopy (top-right and bottom) and radiography (top-left) screens and the simulation of the lithotripsy procedure.*

The developed training platform provides two different views: the endoscope monitor displaying real time intraoperative images and a remote view of the patient body equivalently to the radiographic acquisition (see Figure 4). The equivalent X-rays view is only updated when required by the surgeon and allows the specialist to know the current exact location of the endoscope.

4. Conclusions

To offer a solution to the drawbacks associated to the conventional flexible ureterorenoscopy technique, the LITHOS project provides a novel system that allows the remote control of the flexible endoscope by the use of robotics as an alternative to this type of interventions, meeting the needs of both patients and surgeons.

The implemented training virtual platform for LITHOS project has been presented in this work. It replicates the same interface of the robotic system, including the endoscope controllers operated by the specialists and the lithotripsy procedure. The developed virtual environment offers a suitable tool for the training of urologic surgeons manipulating the LITHOS system in flexible ureterorenoscopy interventions for the first time.

Acknowledgements

This work was supported by the “Ministerio de Economía, Industria y Competitividad” within the framework of the project “LITHOS: Cirugía Robótica para el Tratamiento de Cálculos Renales” (RTC-2016-5338-1). Authors acknowledge support for Robotics Special Applications S.L., Vicomtech-IK4 and the Instituto de Investigación Sanitario Biodonostia.

References

[1] JAFFRAY, B. Minimally invasive surgery. *Archives of disease in childhood*, 2005, vol. 90, no 5, p. 537-542.

[2] SMITHERS, Bernard M., et al. Comparison of the outcomes between open and minimally invasive esophagectomy. *Annals of surgery*, 2007, vol. 245, no 2, p. 232.

[3] LACY, Antonio M., et al. The long-term results of a randomized clinical trial of laparoscopy-assisted versus open surgery for colon cancer. *Annals of surgery*, 2008, vol. 248, no 1, p. 1-7.

[4] GUILLOTREAU, Julien, et al. Radical cystectomy for bladder cancer: morbidity of laparoscopic versus open surgery. *The Journal of urology*, 2009, vol. 181, no 2, p. 554-559.

[5] FUCHS, K. H. Minimally invasive surgery. Endoscopy, 2002, vol. 34, no 02, p. 154-159.

[6] PARK, Adrian, et al. Patients benefit while surgeons suffer: an impending epidemic. *Journal of the American College of Surgeons*, 2010, vol. 210, no 3, p. 306-313.

[7] MILLER, Kristen, et al. Ergonomics principles associated with laparoscopic surgeon injury/illness. *Human factors*, 2012, vol. 54, no 6, p. 1087-1092.

[8] CADIERE, Guy-Bernard, et al. Feasibility of robotic laparoscopic surgery: 146 cases. *World journal of surgery*, 2001, vol. 25, no 11, p. 1467-1477.

[9] MAESO, Sergio, et al. Efficacy of the Da Vinci surgical system in abdominal surgery compared with that of laparoscopy: a systematic review and meta-analysis. 2010.

[10] FANFANI, Francesco, et al. The new robotic TELELAP ALF-X in gynecological surgery: single-center experience. *Surgical endoscopy*, 2016, vol. 30, no 1, p. 215-221.

[11] LUM, Mitchell JH, et al. The RAVEN: Design and validation of a telesurgery system. *The International Journal of Robotics Research*, 2009, vol. 28, no 9, p. 1183-1197.

[12] SU, Li-Ming, et al. Robotic percutaneous access to the kidney: comparison with standard manual access. *Journal of Endourology*, 2002, vol. 16, no 7, p. 471-475.

[13] KIEMENEIJ, Ferdinand, et al. Use of the Stereotaxis Niobe® magnetic navigation system for percutaneous coronary intervention: Results from 350 consecutive patients. *Catheterization and Cardiovascular Interventions*, 2008, vol. 71, no 4, p. 510-516.

[14] DESAI, Mihir M., et al. Flexible robotic retrograde renoscopy: description of novel robotic device and preliminary laboratory experience. *Urology*, 2008, vol. 72, no 1, p. 42-46.

[15] SAGLAM, Remzi, et al. A new robot for flexible ureteroscopy: development and early clinical results (IDEAL stage 1–2b). *European urology*, 2014, vol. 66, no 6, p. 1092-1100.

[16] SCALES, Charles D., et al. Prevalence of kidney stones in the United States. *European urology*, 2012, vol. 62, no 1, p. 160-165.

[17] ROUTH, Jonathan C.; GRAHAM, Dionne A.; NELSON, Caleb P. Epidemiological trends in pediatric urolithiasis at United States freestanding pediatric hospitals. *The Journal of urology*, 2010, vol. 184, no 3, p. 1100-1105.

[18] TÜRK, Christian, et al. EAU guidelines on interventional treatment for urolithiasis. *European urology*, 2016, vol. 69, no 3, p. 475-482.

[19] BEIKO, Darren T.; DENSTEDT, John D. Advances in ureterorenoscopy. *Urologic Clinics of North America*, 2007, vol. 34, no 3, p. 397-408.

[20] BREDA, Alberto, et al. Flexible ureteroscopy and laser lithotripsy for multiple unilateral intrarenal stones. *European urology*, 2009, vol. 55, no 5, p. 1190-1197.

[21] AL BAREEQ, Reem, et al. The role of surgical simulation and the learning curve in robot-assisted surgery. *Journal of robotic surgery*, 2008, vol. 2, no 1, p. 11-15.

[22] MICHEL, Maurice Stephan, et al. The URO Mentor: development and evaluation of a new computer-based interactive training system for virtual life-like simulation of diagnostic and therapeutic endourological procedures. *BJU international*, 2002, vol. 89, no 3, p. 174-177.

[23] WIGNALL, Geoffrey R., et al. Surgical simulation: a urological perspective. *The Journal of urology*, 2008, vol. 179, no 5, p. 1690-1699.

[24] CHAI3D website. http://www.chai3d.org/ (Accessed: September 2017).

[25] MÜLLER, Matthias, et al. Position based dynamics. *Journal of Visual Communication and Image Representation*, 2007, vol. 18, no 2, p. 109-118.

[26] MÜLLER, Matthias, et al. Meshless deformations based on shape matching. *ACM transactions on graphics (TOG)*, 2005, vol. 24, no 3, p. 471-478.