Robotic surgery in gynecology

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Summary

Robotic technology is nothing more than an enhancement along the continuum of laparoscopic technological advances and represents only the beginning of numerous more forthcoming advances. It constitutes a major improvement in the efficiency, accuracy, ease, and comfort associated with the performance of laparoscopic operations.

Instrument articulation, downscaling of movements, absence of tremor, 3-D image, and comfort for the surgeon, assistant and scrub nurse are all new to the practice of laparoscopy. In our hands, robotic operative times for simple and radical hysterectomy are shorter than those obtained by conventional laparoscopy. Robotic technology is preferable to conventional laparoscopic instrumentation for the surgical treatment of gynecologic malignancies and most operations for benign disease of certain complexity such as hysterectomy myomectomy, and invasive pelvic endometriosis.

Key words: Robotics; Gynecology; Hysterectomy.

Introduction

Laparoscopic technology has evolved since its early inception. A great advance was signified by the switch from a monocular direct vision through the laparoscope to the indirect 2-D image of the laparoscopic field projected onto a monitor screen. Surgeons had to develop a set of new visual-manual coordination skills through a long anti-intuitive process, since the movement of the tip of the instruments is opposite to the movement of the hand: moving the tip of the instrument to the right requires opposite movement of the operating hand, to the left, and similarly with vertical movements.

The introduction of fiberoptics resulted in a superior lighting system. The 5 mm scope was widened to 10 mm in diameter. The image resulting from a large single-chip camera markedly improved when a small three-chip camera became available. Recently, a flexible scope containing a chip at its distal tip has allowed visualization of structures over large organs or distended bowel. We all have incorporated technological advances into our laparoscopic practice without requiring objective evidence of their superiority. They were simply superior to what we had available.

Robotic technology is no more than a giant step in the continued evolution of laparoscopic technology. It was designed to facilitate laparoscopic surgery by improving precision, efficiency and comfort. Experience has shown this to be the case.

There are three robotic systems available for surgical gynecology: one to control the laparoscope, one to control the laparoscope and articulated instruments for the performance of laparoscopic operations, and one for telementoring. They will be reviewed here.

AESOP

AESOP (automated endoscopic system for optimal positioning) (Computer Motion, Inc., Goleta, CA, now owned by Intuitive Surgical, Inc., Sunnyvale, CA), is a voice-activated robotic arm designed to operate the laparoscope. It was released in 1994 and was the first robotic device to be cleared by the FDA (Food and Drug Administration) to assist in laparoscopic procedures. The operating surgeon controls the movements and operation of the laparoscope via specific voice commands previously registered on a magnetic card with his/her own voice.

We incorporated AESOP in our gynecologic practice in 1997, and it is still being used for conventional laparoscopic operations. Shortly thereafter, AESOP was improved with the addition of a second articulated joint (second generation AESOP). The additional joint increased the excursion of the arm and resulted in expansion of the laparoscopic field without having to reposition its attachment along the side rail of the operating table.

AESOP provides several functions, previously unavailable in laparoscopic surgery. The usual tremor or shakiness associated with the human hand is eliminated, resulting in a perfectly still image of the surgeon's choice. There are no unwanted or unnecessary movements or fatigue. The quality of videotaping is improved. It replaces the need of an assistant in simple operations and, in complex operations, the assistant has a free hand to facilitate other functions,

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such as operating additional instruments or a uterine manipulator. The image of the operating field is independent of the expertise of the assistant. There is a short learning curve before voice commands become second nature.

Zeus Micro Wrist Surgical System (Figure 1)

The natural evolution of AESOP was to expand from one robotic arm to three. While the laparoscope was still voice activated, two additional robotic arms were implemented to operate robotic instruments telemanipulated by the surgeon sitting at a distance from the operating table. The operating robotic arms were attached to the side rails of the operating table, at the level of the patient's knees for pelvic surgery and at the patient's shoulder level for procedures in the upper abdomen such as aortic node dissection, omentectomy and diaphragm biopsies. Foot switches were used to activate and deliver monopolar current to the robotic coagulating scissors and to disengage the robotic instruments when needed to return to an ergonomic position of the surgeon arms. This was the birth of Zeus Micro Wrist Surgical System (Computer Motion, Inc., Goleta, CA now owned by Intuitive Surgical, Inc., Sunnyvale, CA). Zeus manufacturing was discontinued following the acquisition of Computer Motion, Inc. by Intuitive Surgical, Inc.

Our robotic practice continued with the da Vinci Surgical System which was an innovative tool offering several advantages in a single system. The tip of the robotic instrument was articulated through a single joint, allowing a fifth degree of motion, and facilitating tissue dissection. The surgeon sat comfortably at a console. Tremors or shakiness of the operating human hand were filtered through a computerized electronic controller resulting in accurate and precise instrument movements and facilitating gentle tissue dissection. The surgeon's movements were downscaled at a ratio of 5:1 (for every 5 cm of movement of the control handles, the robotic instruments traveled a distance of 1 cm). The projected image became three-dimensional to the surgeon by the application of special polarizing glasses. No tactile feedback (haptic) was offered.

The conversion of the movements of the surgeon's hands to analog signals offered the potential for digital transmission to any location in the globe thus making it possible to perform surgeries on patients remotely (telesurgery; telerobotics) (see below).

We employed the Zeus robotic system for gynecologic operations from February 20, 2003 to January 16, 2004. In our experience with Zeus, there were no intraoperative injuries or conversions to laparotomy in a total of 61 patients. A list of the procedures performed with Zeus is provided in Table 1.

Table 1. — *Robotic gynecological operations performed in 62 patients using the Zeus Micro Wrist Surgical System between February 2003 and January 2004.*

Type of operation	No. performed
Salpingo-oophorectomy	
Bilateral	15
Unilateral	9
Hysterectomy	
With BSO	11
Radical with BSO	2
Subtotal	1
Lymphadenectomy	
Pelvic	8
Aortic	6
Pelvic and aortic	4
Excision of endometriosis	7
Ureterolysis	7
Bilateral salpingectomy	6
Ovarian cystectomy	5
Myomectomy	4
Upper vaginectomy	2
Other	26

BSO, bilateral salpingo-oophorectomy.

Robotic uterine horn anastomosis, adnexal surgery and hysterectomy were reported as feasible in female pigs [1, 2]. Tubal reanastomosis was reported in ten patient post-tubal ligations [3]. Total operating times were 284 ± 49.5 min, and there were no intraoperative complications. Tubal patency was documented in 89% of patients.

da Vinci Surgical System (Figure 2)

On July 11, 2000, the U.S. Food and Drug Administration (FDA) approved the da Vinci Surgical System for the performance of procedures in the abdominal and pelvic cavity. In 2003 and 2004 FDA approval was obtained for cardiac surgery, specifically for mitral valve replacement and coronary artery bypass. In 2005, it received specific FDA approval for the performance of robotic hysterectomy. The da Vinci robotic system (Intuitive Surgical, Inc., Sunnyvale, CA) is an improved robotic system from its previous competitor Zeus Micro Wrist Surgical System. There are about 350 robotic systems operating in the world at the present and this number is increasing daily.

The surgeon is seated at a console away from the operating table telemanipulating the laparoscope and two or three robotic instruments with the assistance of hands and feet. Foot switches are used to activate monopolar and bipolar electrical currents to the robotic instruments, inclusive of a vessel sealing instrument (Endowrist PK dissecting forceps), to activate a harmonic instrument (Harmonic curved shears), to operate the laparoscope, to focus the image, and to disengage the robotic arms from the surgeon's hands. The scrub nurse and assistant (if needed) are seated at each side of the operating table.

The da Vinci system offers several advantages over Zeus and constitutes a major advancement in laparoscopic technology. The operating surgeon has an improved, crystal clear three-dimensional view of the operating field without the need of polarizing glasses. Downscaling of the surgeon's movements can be selected at several ratios, 5:1, 3:1 or 1:1. Movement downscaling results in improved surgeon accuracy and precision, while filtering of hands tremor appears to have a lesser role for accuracy [4].

The tip of the robotic instruments allows seven degrees of freedom, surpassing the movements of the human wrist. Two articulations within 2 cm of the instrument tips provide 360° rotation and flexion. The articulated ends can be directed to the appropriate plane for precise tissue dissection, instead of forcing the tissues to align in the direction of rigid instruments. During suturing, the needle can easily be positioned in any direction, allowing accurate placement of the sutures. This results in gentle and precise tissue dissection, effortless suturing and intracorporeal knot tying, and improved suturing accuracy [5, 6].

In contrast to conventional laparoscopy, the robotic instruments are designed to follow the movement of the surgeon's hands: an upward or downward movement of the hand is followed in the same direction by the robotic instrument. Similarly, hand movements to the right or left are equally followed in the same direction by the robotic instruments. In conventional laparoscopy, hand movements are translated into opposite movements at the tip of the rigid instruments. This is one of the several reasons why robotics has a shorter learning curve, faster times, and reduced errors than conventional laparoscopy [7, 8].

The lack of haptics or tactile feedback is easily compensated by viewing on the three-dimensional image the pressure or pulling effect of the robotic instruments upon the patient tissues. Robotic instrumentation is most useful in morbidly obese patients because the operating surgeon feels no resistance to the movement of the robotic instruments through the thick abdominal wall. The surgeon effort is the same regardless of the weight of the patient. In our series of 91 robotic hysterectomies, the patients' body mass index (BMI) did not influence operating times [9].

A second generation of the da Vinci Surgical System (da Vinci S; Intuitive Surgical Inc., Sunnyvale, CA) was released in January 2006. Control handles and foot switches remain unchanged. However, the instruments are 5 cm longer, the robotic arms are narrower and their flexion-extension and lateral excursion is increased by 80% and 200%, respectively, expanding the range of movement and the operating field. The advancement of the robotic column is motor powered. The surgeon's 3-D screen contains small sub-windows providing patient information, such as vital signs, and visualization of the operating table or room without removing the head from the viewing site.

Comparison of robotic versus laparoscopic skills

Studies comparing laparoscopic versus robotic performance in laboratory drills have shown improved accuracy, faster intracorporeal knot tying, reduction of errors, and a shorter learning curve with robotic assistance.

Studies using training models have shown improved suturing precision and faster intracorporeal knot tying with robotic systems as compared to conventional laparoscopy [5, 6]. Robotic assistance resulted in a statistically significant difference in the learning curves of two sets of trials as compared to conventional laparoscopy [10]. In another study comparing laparoscopy and robotic suturing, the articulation and motion scaling of the robotic instruments enhanced dexterity by 50% and the 3D vision improved it by a further 10-15%. The latter resulted in a 93% reduction in skill-based errors [11]. Non-experienced laparoscopists obtained faster intracorporeal knot tying skills than experienced laparoscopists using robotic technology. Both showed faster times and reduced errors after a four to six hour period of using robotic technology [7]. Faster times were noted in the performance of a series of drills with robotic technology as compared to laparoscopy. Novice laparoscopic surgeons had faster performance in three out of four drills as compared to expert laparoscopic surgeons, emphasizing a fast learning curve using robotic technology [8].

Telesurgery and telerobotics

The first transatlantic telesurgical operation was performed September 7, 2001 by a surgeon in New York City on a patient in Strasbourg, France [12]. The operation was a cholecystectomy and the Zeus Micro Wrist Surgical System was used. Anvari *et al.*, [13] recently reported 21 successful telesurgeries between Hamilton and North Bay (Ontario, Canada), located more than 400 km apart, using the Zeus robotic system. Telerobotics is performed on a weekly basis between both hospitals. It provides highly specialized operations to a rural hospital.

It requires a central operating surgeon, a remote surgeon (who places the trocars on the patient, docks the robotic system, assists through an additional trocar site and changes instruments), and a telecommunication link between both sites. A bandwidth of 15 Mbps with QoS (quality of service) is used in the Canadian service. The surgical signal takes priority over any other signal in the network. In addition, there is an active backup line, should there be a failure of the first one. Latency of the transmission, 135-140 ms, is the major obstacle for the operating surgeon. Slowing of the surgeon movements is necessary to surmount this deficiency.

Telementoring (Figure 3)

A telementoring or telesurgical mentoring system allows a surgical specialist to guide a remote surgeon during the performance of a procedure. On April 8, 1997 the first intercontinental telementoring was performed between Baltimore, Maryland and Innsbruck, Austria [14]. It has been shown by others to be efficient for performing and/or teaching laparoscopic or robotic procedures at remote sites [14-16].

Socrates (Computer Motion, Inc., Goleta, CA, now owned by Intuitive Surgical, Inc., Sunnyvale, CA) allows a central surgeon to communicate via video and audio with a remote site and to guide the operating surgeon via telestration and control of the AESOP arm. We have had such system available at our institution since 2003, and it provides a connection between an operating room at our hospital and our outpatient clinic located 14 miles away.

Fig. 1

Fig.

Fig. 2

Figure 1. — Zeus Micro Wrist Surgical System. The two robotic arms are attached at each side rail of the operating table. AESOP is attached on the right side rail at the level of the patient's shoulders and is holding the laparoscope.

Figure 2. — Da Vinci Surgical System. The robotic column is situated between the patient's legs. The two lateral robotic arms are connected to the lateral pelvic trocars. The central arm is holding the laparoscope.

Figure 3. — Socrates System. This monitor at our Outpatient Clinic facility is connected to an operating room at our Hospital 12 miles away for occasional teleconsultations. Telestration and voice interaction is used to provide an intraoperative consultation or guide the operating fellow.

Another telementoring system [16] allows the central surgeon to control the electrocautery in addition to the scope. In another, the central surgeon, using the Zeus robotic system, is assisting the remote surgeon who is operating with conventional laparoscopic instruments (teleproctoring) [13]. Two surgeons located at two different hospitals can participate in the same operation with each performing a different part of the procedure.

Telementoring systems are helpful for graduating residents moving to remote areas where no senior supervision may be accessible, for gynecologists who wish to advance their laparoscopic skills under supervision by an expert, for gynecologists performing a recently learned operation for first time (teleproctoring), or in situations where an intraoperative consultation may be needed from a subspecialist (teleconsultation).

Gynecological experience

The da Vinci system has been used for cardiovascular, general and in particular urological procedures. Gynecologists began using the system more recently. Publications include hysterectomy, myomectomy, tubal reanastomosis, sacrocolpopexy, and vesicovaginal fistula repair.

The first published report of hysterectomy was on January 29, 2001. A review of the first ten robotic hysterectomies by the same author indicated operative times of 4.5-10 hours, estimated blood loss 50-1000 ml, and mean hospitalization of one to three days [17]. Robotic repair of the vesicovaginal fistula was successful in five patients (18). Operating times were a mean of 233 min (range 150-330), mean blood loss was 70 ml (range not reported), and the mean hospital stay was five days (range 4-7).

Other reports have dealt with robotic operations with vaginal or laparoscopic assistance but not performed entirely robotically. One of them reported 23 robotic assisted-vaginal hysterectomies and six robotic hysterectomies [19] with operating times ranging from 43-315 min (mean 185), mean blood loss of 83 ml (range 0-900), and mean hospitalization of eight days (range 4-33). In another study of 20 patients undergoing sacrocolpopexy, conventional laparoscopy was used for dissection while robotic assistance was used only for suturing the mesh [20]. In a case report of vesicovaginal fistula repair, conventional laparoscopy was used for dissection while robotic assistance was used for suturing the defect [21].

Mayo Clinic experience

Between February 20, 2003 and August 14, 2006 we performed robotic surgery, without vaginal or laparoscopic assistance, in a total of 406 patients, including 142 who were treated for primary or recurrent gynecologic cancer. Robotic systems used included 62 operations with the Zeus Micro Wrist robotic system (Table 1) while the remaining were performed with the da Vinci surgical system.

Included among the da Vinci operations are simple, modified radical and radical hysterectomies, radical parametrectomy, radical vaginectomy, pelvic and aortic lymphadenectomy, supracolonic omentectomy, diaphragm resection, modified posterior pelvic exenteration, rectosigmoid resection, small bowel resection, resection of peritoneal tumor metastases, pelvic peritonectomy, myomectomy, adnexectomy, excision of invasive pelvic endometriosis, partial bladder resection, presacral neurectomy, sacrocolpopexy, uterosacral ligament suspension, ovarian cystectomy, and repair of bladder, ureter, small bowel, rectosigmoid and vena cava injuries.

We have noted reduced operating times and blood loss for simple and radical hysterectomies using the da Vinci system as compared to conventional laparoscopy. We also observed reduced hospitalization for radical hysterectomy patients.

We recently reviewed a series of 91 patients undergoing robotic simple hysterectomy at our institution (9). Mean docking time (time to attach the robotic arms to the trocars) was 2.95 min (range 1-9). Mean console time – the surgeon's time dedicated exclusively to the performance of the hysterectomy – was 73 min (range 30-191). Console time increased with uterine weight (mean uterine weight 135 gm, range 18-366) and the presence of adhesions but not with patients' BMI. Total operating time (skin to skin) was 122 min, 14 minutes shorter as compared to laparoscopy. Mean estimated blood loss was 79 ml (range 20-200). Mean hospital stay was 1.3 days (range 0-4). There was only one intraoperative complication, an enterotomy which was repaired robotically. Postoperative complications were noted in two patients, one with cardiomyopathy who required admission to intensive care for 24 hours and one for a vaginal cuff abscess. Single instances were noted for ileus, pneumonia, and colitis, requiring readmission.

Robotic radical hysterectomy total operating time for eight patients was 218 minutes, of which 174 were console time. Total operating time was 66 minutes shorter than our previously reported experience with laparoscopic radical hysterectomy [22]. As compared to laparoscopy, robotic patients experienced reduced blood loss (176 vs 328 ml) and reduced hospitalization (1.9 vs 2.9 days). Lymph node count was higher for the laparoscopy group (27.9 vs 24). There were no intraoperative or major postoperative complications in either group [23].

Conclusions

The da Vinci robotic system has introduced numerous new technological advancements, not simply improvements, in a single system. Instrument articulation, downscaling of movements, absence of tremor, 3-D image, and comfort for the surgeon, assistant and scrub nurse are all new to the practice of laparoscopy. The system constitutes a major improvement in the efficiency, accuracy, ease, and comfort associated with the performance of laparoscopic operations. Robotic technology is nothing more than an enhancement along the continuum of laparoscopic technological advances and represents only the beginning of numerous more forthcoming advances.

Robotic surgery is preferable to conventional laparoscopy for gynecologic oncology procedures and most gynecological operations of certain complexity such as hysterectomy, myomectomy, and invasive pelvic endometriosis. In our institution, robotics is a daily occurrence with gynecological, urological or general surgery operations.

Telesurgery and telementoring, already a reality, will provide a new approach to the performance of difficult laparoscopic operations or for operations in remote areas, and for the teaching or supervision of complex laparoscopic operations, respectively.

References

[1] Margossian H., Falcone T.: "Robotically assisted laparoscopic hysterectomy and adnexal surgery". *J. Laparoendosc Adv. Surg. Tech. A.*, 2001, *11*, 161.
[2] Margossian H., Garcia-Ruiz A., Falcone T., Goldberg J.M., Attaran M., Gagner M.: "Robotically assisted laparoscopic microsurgical uterine horn anastomosis". *Fertil. Steril.*, 1998, *70*, 530.
[3] Falcone T., Goldberg J.M., Margossian H., Stevens L.: "Robotic-assisted laparoscopic microsurgical tubal anastomosis: a human pilot study". *Fertil. Steril.*, 2000, *73*, 1040.
[4] Prasad S.M., Prasad S.M., Maniar H.S., Chu C., Schuessler R.B., Damiano R.J. Jr.: "Surgical robotics: impact of motion scaling on task performance". *J. Am. Coll. Surg.*, 2004, *199*, 863.
[5] Dakin G.F., Gagner M.: "Comparison of laparoscopic skills performance between standard instruments and two surgical robotic systems". *Surg. Endosc.,* 2003, *17*, 574.
[6] De Ugarte D.A., Etzioni D.A., Gracia C., Atkinson J.B.: "Robotic surgery and resident training". *Surg. Endosc.*, 2003, *17,* 960.
[7] Chang L., Satava R.M., Pellegrini C.A., Sinanan M.N.: "Robotic surgery: identifying the learning curve through objective measurement of skill". *Surg. Endosc.*, 2003, *17*, 1744.
[8] Sarle R., Tewari A., Shrivastava A., Peabody J., Menon M.: "Surgical robotics and laparoscopic training drills". *J. Endourol.*, 2004, *18*, 63.
[9] Kho R., Magtibay P., Magrina J.F.: "Robotic hysterectomy: morbidity and results". *Submitted to Am J Obstet Gynecol.,* 2006.
[10] Yohannes P., Rotariu P., Pinto P., Smith A.D., Lee B.R.: "Comparison of robotic versus laparoscopic skills: is there a difference in the learning curve?". *Urology,* 2002, *60*, 39.

[11] Moorthy K., Munz Y., Dosis A., Hernandez J., Martin S., Bello F., *et al.*: "Dexterity enhancement with robotic surgery". *Surg. Endosc.,* 2004, *18,* 790.
[12] 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.
[13] Anvari M., McKinley C., Stein H.: "Establishment of the world's first telerobotic remote surgical service: for provision of advanced laparoscopic surgery in a rural community". *Ann. Surg.*, 2005, *241,* 460.
[14] Janetschek G., Bartsch G., Kavoussi L.R.: "Transcontinental interactive laparoscopic telesurgery between the United States and Europe". *J. Urol.,* 1998, *160*, 1413.
[15] Rodrigues Netto N. Jr., Mitre A.I., Lima S.V., Fugita O.E., Lima M.L., Stoianovici D. *et al.*: "Telementoring between Brazil and the United States: initial experience". *J. Endourol.*, 2003, *17*, 217.
[16] Schulam P.G., Docimo S.G., Saleh W., Breitenbach C., Moore R.G., Kavoussi L.: "Telesurgical mentoring. Initial clinical experience". *Surg. Endosc.*, 1997, *11*, 1001.
[17] Diaz-Arrastia C., Jurnalov C., Gomez G., Townsend C. Jr.: "Laparoscopic hysterectomy using a computer-enhanced surgical robot". *Surg. Endosc.,* 2002, *16,* 1271.
[18] Sundaram B.M., Kalidasan G., Hemal A.K.: "Robotic repair of vesicovaginal fistula: case series of five patients". *Urology,* 2006, *67,* 970.
[19] Marchal F., Rauch P., Vandromme J., Laurent I., Lobontiu A., Ahcel B. *et al.*: "Telerobotic-assisted laparoscopic hysterectomy for benign and oncologic pathologies: initial clinical experience with 30 patients". *Surg. Endosc.*, 2005, *19*, 826.
[20] Elliott D.S., Frank I., Dimarco D.S., Chow G.K.: "Gynecologic use of robotically assisted laparoscopy: Sacrocolpopexy for the treatment of high-grade vaginal vault prolapse". *Am. J. Surg.*, 2004, *188*, (suppl. 4A), 52S.
[21] Melamud O., Eichel L., Turbow B., Shanberg A.: "Laparoscopic vesicovaginal fistula repair with robotic reconstruction". *Urology,* 2005, *65*, 163.
[22] Magrina J.F.: "Laparoscopic surgery for gynecologic cancers". *Clin. Obstet. Gynecol.,* 2000, *43,* 619.
[23] Magrina J.F., Kho R., Magtibay P.: "Comparison of robotic, laparoscopic and open radical hysterectomy". Unpublished data, 2006.

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