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SURGICAL ENDOSCOPY
and Other Interventional Techniques

Advantages and limits of robot-assisted laparoscopic surgery

Preliminary experience

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Abstract
Background: In the last few years, robotics has been applied in clinical practice for a variety of laparoscopic procedures. This study reports our preliminary experience using robotics in the field of general surgery to evaluate the advantages and limitations of robot-assisted laparoscopy.
Methods: Thirty-two consecutive patients were scheduled to undergo robot-assisted laparoscopic surgery in our units from March 2002 to July 2003. The indications were cholecystectomy, 20 patients; right adrenalectomy, two points; bilateral varicocelectomy, two points; Heller's cardiomyotomy, two points; Nissen's fundoplication, two points; total splenectomy, one point; right colectomy, one point; left colectomy, 1 point; and bilateral inguinal hernia repair, one point. In all cases, we used the da Vinci surgical system, with the surgeon at the robotic work station and an assistant by the operating table.
Results: Twenty-nine of 32 procedures (90.6%) were completed robotically, whereas three were converted to laparoscopic surgery. Conversion to laparoscopy was due in two patients to minor bleeding that could not be managed robotically and to robot malfunction in the third patient. There were no deaths. Median hospital stay was 2.2 days (range, 2–8).
Conclusions: The main advantages of robot-assisted laparoscopic surgery are the availability of three-dimensional vision and easier instrument manipulation than can be obtain with standard laparoscopy. The learning curve to master the robot was ≥ 10 robotic procedures. The main limitations are the large diameter of the instruments (8 mm) and the limited number of robotic arms (maximum, three). We consider these technical shortcomings to be the cause for our conversions, because it is difficult to manage bleeding episodes with only two operating instruments. The benefit to the patient must be evaluated carefully and proven before this technology can become widely accepted in general surgery.

Key words: Robotics — Laparoscopy — da Vinci surgical robot

In the 1990s, the advent of laparoscopic surgery led to enormous advances in the field of general surgery. However, the new laparoscopic procedures also had its disadvantages, including an unstable camera platform, the limited mobility of straight laparoscopic instruments, two-dimensional imaging, and a poor ergonomic position for the surgeon [1, 21]. For this reason, much attention is now being paid to the promise of robotic surgery [2]. In the last few years, a number of articles have been published on the performance of surgical procedures using robot-assisted laparoscopy [1, 9, 10]. Robotic technology provides a stable camera platform, replaces two-dimensional with three-dimensional (3-D) imaging, simulates the fluid movements of a surgeon's wrist to overcome the limited mobility imposed by the use of straight laparoscopic instruments, and offers the surgeon a comfortable and ergonomically optimal operating position [1, 19].

We reviewed our early clinical experience with robotic surgery to assess its advantages and current limitations on the basis of our large experience in laparoscopic surgery.

Patients and methods

The study population consisted of 32 consecutive elective patients who were scheduled to undergo robot-assisted laparoscopic surgery in our units from March 2002 to July 2003. There were 19 men and 13 women with ages ranging from 23 to 76 years (median, 47). Of these 32 patients, 20 underwent cholecystectomy; two, right adrenalectomy; two, bilateral varicocelectomy; two, Heller's cardiomyotomy; two, Nissen's

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fundoplication; one, total splenectomy; one, right colectomy; one, left colectomy; and one, bilateral inguinal hernia repair.

In all cases, we used the da Vinci (Intuitive Surgical Inc, Sunnyvale, CA, USA) surgical system, with the surgeons at the robotic work station, an assistant by the operating table, and the robot located on the side of the operating table. The robot is connected to the three operative trocars, not to the operating table. Da Vinci offers a true 3-D imaging system very much similar to the vision provided by field binoculars. The telescope is 12 mm in diameter and contains two separate 5-mm telescopes. Two three-chip video cameras telecast the image on two separate CRT screens. A synchronizer keeps the images from the two cameras in phase. Mirrors reflect the images from the CRT screens up to the binocular viewer in the surgeon's console. This allows the left and right images to remain separate from the telescopes to the surgeon's eyes. As with binoculars, the right eye sees the right image and the left eye sees the left image.

In all patients, we used a 12-mm da Vinci optic operated by a voice control system and two 8-mm trocars. Robotic instruments move with seven degrees of freedom and two degrees of axial rotation. The surgical instruments are partially reusable; they can be used 10 times. The telerobot's computer tracks the number of times each instrument has been used and will not work after the 10^{th} use. The instruments are positioned according to the surgical procedures to be performed. In 29 of the 32 cases, we used an additional 5-mm trocar, which was kept in place by the assistant at the operating table. All of our surgeons had wide experience in laparoscopy and had undergone a 3-week training period on the da Vinci system, on a pelvic trainer, and with an experimental animal model.

Results

There were no deaths in our series, and the median hospital stay was 2.2 days (range 2–8). Twenty-nine procedures (90.6%) were completed robotically, whereas three required conversion to standard laparoscopy. The causes for conversion were in two cases mild bleeding that could not be managed with the robot (one from the splenic artery during a splenectomy and one from the cystic artery during a cholecystectomy); whereas in one case, conversion was due to malfunction of the robot.

Median time to position the robot for the first 15 procedures was 45 min, but it dropped to 20 min for the last 17 procedures. When this aspect was analyzed statistically using an unpaired *t*-test, the difference was found to be statistically significant ($p = 0.0208$).

Discussion

With the advent of laparoscopy at the end of the 1980s, surgery entered the computer age [4, 5, 11]. The magnified and computer-enhanced video images provided surgeons with much better exposure and visualization of the abdomen. In any case, most laparoscopic gastrointestinal operations are difficult to learn, master, and perform routinely [6, 14, 15]. Surgeons face a long learning curve. Moreover, a number of pitfalls inherent to laparoscopy still hamper the performance of advanced laparoscopic procedures, including an unstable camera platform, the limited mobility of straight laparoscopic instruments, two-dimensional imaging, and a poor ergonomic position for the surgeon [1, 3, 16].

Frustration with these limitations paved the way for robotic surgery. The integration of robotics with laparoscopic surgery has led to the development and improvement of videosurgical performances. The aim of our study was to analyze our preliminary experience with robotic surgery on the basis of our large experience with laparoscopic surgery. The advantages and limitations of robotic surgery compared to laparoscopy are summarized in Table 1.

Table 1. Advantages and limitations of robotic surgery compared to laparoscopy

Aspects evaluated	Robotic surgery	Laparoscopy
Vision	Three-dimensional	Two-dimensional
Instrument manipulation	360°	Limited
Costs	Extremely high	Lower
Assembly	Extremely long	Faster
Ergonomics	Very good (like the human wrist)	Poor
No. of ports	3	≥3
Port diameter	8 mm	≥2 mm
Diffusion in clinical practice	Rare	In all surgical centers

As if now stands, we think that the performance of the robotic system used by our team can certainly be improved, because it still has many limitations [8, 19]. First of all, the cost of the robot itself and the instruments — which have to be changed after every 10 operations — are by no means negligible [1, 13, 18]. In addition, the da Vinci system is rather cumbersome; it fills a large operating room, and its use in smaller rooms is therefore impractical [2, 12, 17]. As a matter of fact, we have had to modify the arrangement of the instruments and furniture of our main operating room to bring in the da Vinci system and allow sufficient space around it and it was impossible to make the same modifications in our secondary operating room due to its small size. Moreover, the system is very heavy, making it difficult to move it around the room and even more difficult to transfer it to another operating room [2, 20]. Changing the setup of the operating room according to the type of operation being performed (cholecystectomy requires a different setup from achalasia or colon resection, for instance) is time consuming and tiring. Storage outside the operating theater requires a small room.

Moreover, because da Vinci was designed specifically for cardiac surgery, the requirements for abdominal surgery were not taken into account [1, 11, 16]. As a result, the use of a da Vinci for abdominal surgery presents a variety of challenges. The instrumentation available is limited; the robotic arms are bulky and are not attached to the operating table [3, 19]. Large excursion arcs of the arms lead to frequent collisions. The strong robotic arms lack tensile feedback. Use of the telerobot in standard operating rooms can be extremely difficult.

Because the current generation of da Vinci does not provide tensile feedback, the surgeon must rely on visual clues to estimate the tension placed on tissues by da Vinci's powerful robotic arms [4, 9]. Inexperienced telerobotic surgeons can easily avulse tissues with the robotic arms if they fail to perceive these subtle visual clues, as happened in one of our early interventions, despite our long experience with laparoscopy [1, 12]. Nor does the surgeon have any indication of how tightly the instruments are grasping the tissues. This situation can lead to suture fraying or pressure injuries to tissue. However, tensile sensors are commercially available, and future generations of telerobots are likely to incorporate this technology. Nonetheless, the lack of feedback is still a problem with current systems [17, 20].

In laparoscopy, pneumoperitoneum pressure is kept low using gravity; adjustments are made by changing the decubitus of the operating table. But this becomes problematical with robotics, because the robotic arms were engineered to meet the requirements of cardiac surgery, which is performed on patients in a flat, horizontal position. If the surgeon requires extreme positions, such as the Trendelenburg or the reverse Trendelenburg, and thus forces the extreme elevation of one robotic arm and the extreme depression of the other, it could cause a collision of the elbows of the robotic arms [1, 7, 14].

We noticed that pneumoperitoneum pressure during robotic procedures is higher than that used to perform the same procedures in laparoscopy. For this reason, minor misplacement of the trocars away from the ideal positions may severely hinder the performance of operations. Another limitation is the large diameter of the instruments (8 mm) and the limited number of robotic arms (maximum, three) [2, 15]. We think that this these system limitations were the cause for our conversions, because it is difficult to manage a bleeding episode with only two operating instruments.

In any case, our initial experience suggests that robotic surgery is feasible and can be performed safely. The main advantage of robot-assisted laparoscopic surgery is the 3-D vision and better instrument manipulation than can be obtained with laparoscopy [11, 14, 19]. In addition, the surgeon can work in a more ergonomic position compared to the difficult posture that may have to be adopted during a laparoscopic intervention — sometimes even in long-lasting procedures [7, 9].

In terms of the learning curve required to master the use of the robot, in our experience, ≥10 robotic procedures are necessary.

As was the case with laparoscopy 15 years ago, robotics will certainly undergo substantial development in the next decade. The main interest lies in telerobotics, which enables a surgeon to operate at a distance from the operating table, perhaps as far away as another town or continent, as has recently been described in the international literature [1, 9, 10]. However, the benefit to the patient must be carefully evaluated and proven before this technology can become widely accepted in clinical practice.

References

1. Ballantyne GH (2002) Robotic surgery, telerobotic surgery, telepresence, and telementoring: review of early clinical results. Surg Endosc 10: 1389–1402
2. Ballantyne GH, Moll F (2003) The da Vinci telerobotic surgical system: the virtual operative field and telepresence surgery. Surg Clin North Am 6: 1293–1304
3. Cadière GB, Himpens J, Germay O, Izizaw R, Degueldre M, Vandromme J, Capelluto E, Bruyns J (2001) Feasibility of robotic laparoscopic surgery: 146 cases. World J Surg 11: 1467–1477
4. Chapman WH 3rd, Albrecht RJ, Kim VB, Young JA, Chitwood WR Jr (2002) Computer-assisted laparoscopic splenectomy with the da Vinci surgical robot. J Laparoendosc Adv Surg Tech 3: 155–159
5. Goh PM, Lomanto D, So JB (2002) Robotic-assisted laparoscopic cholecystectomy. Surg Endosc 1: 216–217
6. Gould JC, Melvin WS (2003) Telerobotic foregut and esophageal surgery. Surg Clin North Am 6: 1421–1427
7. Horgan S, Vanuno D (2001) Robots in laparoscopic surgery. J Laparoendosc Adv Surg Tech 6: 415–419
8. Hourmont K, Chung W, Pereira S, Wasielewski A, Davies R, Ballantyne GH (2003) Robotic versus telerobotic laparoscopic cholecystectomy: duration of surgery and outcomes. Surg Clin North Am 6: 1445–1462
9. Imme A, Caglia P, Gandolfo L, Cavallaro G, Donati M, Amodeo C (2002) Robotic techniques in laparoscopic surgery. Chir Ital 1: 111–113
10. Jacob BP, Gagner M (2003) Robotics and general surgery. Surg Clin North Am 6: 1405–1419
11. Kim VB, Chapman WH, Albrecht RJ, Bailey BM, Young JA, Nifong LW, Chitwood WR Jr (2002) Early experience with telemanipulative robot-assisted laparoscopic cholecystectomy using da Vinci. Surg Laparosc Endosc Percutan Tech 12: 33–40
12. Marescaux J, Leroy J, Gagner M, Rubino F, Mutter D, Vix M, Butner SE, et al. (2001) Transatlantic robot-assisted telesurgery. Nature 13: 710–714
13. Marescaux J, Smith MK, Folscher D, Jamali F, Malassagne B, Leroy J (2002) Telerobotic laparoscopic cholecystectomy: initial clinical experience with 25 patients. Ann Surg 3: 446–447
14. Merola S, Weber P, Wasielewski A, Ballantyne GH (2002) Comparison of laparoscopic colectomy with and without the aid of a robotic camera holder. Surg Laparosc Endosc Percutan Tech 1: 46–51
15. Rockall TA, Darzi A (2003) Robot-assisted laparoscopic colorectal surgery. Surg Clin North Am 6: 1463–1468
16. Ruurda JP, Broeders IA (2003) Robot-assisted laparoscopic intestinal anastomosis. Surg Endosc 2: 236–241
17. Ruurda JP, Broeders IA, Simmermacher RP, Rinkes IH, Van Vroonhoven TJ (2002) Feasibility of robot-assisted laparoscopic surgery: an evaluation of 35 robot-assisted laparoscopic cholecystectomies. Surg Laparosc Endosc Percutan Tech 12: 41–45
18. Schluender S, Conrad J, Divino CM, Gurland B (2003) Robot-assisted laparoscopic repair of ventral hernia with intracorporeal suturing. Surg Endosc 6: 656–658
19. Stylopoulos N, Rattner D (2003) Robotics and ergonomics. Surg Clin North Am 6: 1321–1337
20. Sung GT, Gill IS (2003) Robotic renal and adrenal surgery. Surg Clin North Am 6: 1469–1482
21. Yohannes P, Rotariu P, Pinto P, Smith AD, Lee BR (2002) Comparison of robotic versus laparoscopic skills: is there a difference in the learning curve? Urology 1: 39–45