Chapter 6

Robot-assisted laparoscopic intestinal anastomosis: an experimental study in pigs
Abstract

Introduction: Robotic telemanipulation systems have been introduced recently to enhance the surgeon's dexterity and visualisation in videoscopic surgery in order to facilitate refined dissection, suturing, and knot tying. The aim of this study was to demonstrate the technical feasibility of performing a safe and efficient robot-assisted handsewn laparoscopic intestinal anastomosis in a pig model.

Methods: Thirty intestinal anastomoses were performed in pigs. Twenty anastomoses were performed laparoscopically with the da Vinci robotic system robot-assisted group), the remaining 10 anastomoses by laparotomy (control group). OR time, anastomosis time and complications were recorded. Effectiveness of the laparoscopic anastomoses was evaluated by postoperative observation of 10/20 pigs of the robot-assisted group for 14 days and by testing mechanical integrity in all pigs by measuring passage, circumference, number of stitches, and bursting pressure. These parameters and anastomosis time were compared to the anastomoses performed in the control group.

Results: In all cases of the robot-assisted group the procedure was completed laparoscopically. The only perioperative complication was an intestinal perforation, caused by an assisting instrument. The median procedure time was 77 min. Anastomosis time was longer in the laparoscopic cases than in the controls (25 vs. 10 min; p < 0.001). Postoperatively, one pig developed an ileus, based on a herniation of the spiral colon through a trocar-port. For this reason it was terminated on the sixth postoperative day. All anastomoses of the robot-assisted group were mechanically intact and all parameters were comparable to those of the control group.

Conclusion: Technical feasibility of performing a safe and efficient robot-assisted laparoscopic intestinal anastomosis in a pig model was repeatedly demonstrated in this study, with a reasonable time required for the anastomosis.

Introduction

Although widely accepted for its merits, videoscopic surgery is known for its limitations regarding the surgeon’s dexterity and depth perception. Working through trocars limits the degrees of freedom of movement and introduces an inverted instrument response and variability in the excursion of the instrument tip, directly related to the part of the instrument that is brought into the body cavity. Besides this, surgeons are confined to an indirect, two-dimensional view of the operative field, inherent in working with a camera system. As a result the natural eye–hand–target working axis is lost 1-3.

These disadvantages hinder surgeons in performing complex surgical manoeuvres during videoscopic surgery, such as challenging dissection and videoscopic suturing. Although many surgical procedures of the digestive tract have been performed laparoscopically, difficult interventions still require considerable skill and time 4,5.

Recently, telemanipulation systems such as the da Vinci (Intuitive Surgical, Sunnyvale, CA) and Zeus (Computer Motion, Goleta, CA) were introduced with the objective of enhancing the surgeon’s view and dexterity during videoscopic procedures 6-8. These systems alleviate most of the previously mentioned disadvantages and should therefore be able to support surgeons in performing sophisticated videoscopic procedures in a precise and efficient way.

This might expand the list of indications for routine laparoscopic surgery and bring high-end procedures such as vascular reconstruction, pancreatic surgery, and completely laparoscopic intestinal resections in a broader perspective. In this study, the efficacy of robot-assisted suturing with the da Vinci system was investigated, with the aim of testing the applicability of this device to supporting laparoscopic digestive tract surgery including a hand-sewn intestinal anastomosis.
Materials and Methods

Thirty female pigs with a median weight of 65 kg (49–90) were operated. The rectum was divided at ±15 cm above the anus and a side-to-side rectal anastomosis was performed. Twenty pigs were operated with the da Vinci robotic telemanipulation system. The initial 10 pigs were terminated directly following surgery (robot-assisted group A). This initial experiment was performed to investigate technical feasibility. The following 10 pigs were operated in a similar way and subsequently observed for 14 days followed by autopsy in order to prove safety of this procedure in experimental set-up (robot-assisted group B). Ten pigs used for training in robot-assisted cardiac surgery underwent an open surgical procedure followed by direct postoperative termination (control group).

Robot-assisted laparoscopic surgical procedure: robot-assisted groups A and B

The da Vinci system was used in both robot-assisted groups. This system integrates two controllers and three footpads in a console, from which the surgeon directly controls two robotic instruments, which are carried by robotic arms. Next to the two arms that hold the instruments, the surgeon controls a third arm, carrying the optical system. The arms are placed on a special cart, positioned directly at the operating table. The da Vinci system increases dexterity by two additional degrees of freedom of motion at the tip of the instruments. A true three-dimensional view of the operative field is provided by a double optic system, with separate images for both eyes.

The animals were operated in the supine Trendelenburg position. After establishing a 14 mmHg pneumoperitoneum with the Veress needle technique, a 12-mm trocar was introduced at the umbilicus to host the camera. Two 8-mm trocars with special adapters for the robotic arms were introduced both in the right and left lower quadrant. A fourth trocar (12 mm) for assisting instruments was placed in between the umbilicus and the right robotic-arm trocar (Figure 1).

For this procedure the robot was positioned at the bottom end of the operating table (Figure 2). The robot was subsequently attached to the camera and instrument trocars.

The surgical procedure started with exposure of the distal colon (±10–14 cm above the peritoneal fold). After dissection of the mesocolon, an endoscopic stapling device (Endopath, Ethicon Endosurgery, Amersfoort, the Netherlands) was introduced through the assisting port to divide the colon. The proximal and distal part of the rectum were placed in a side-to-side position and subsequently incised. A single-layer anastomosis was performed in two steps, with two running Vicryl 4.0 sutures. Individual suture length was 19 cm.
Figure 1
Trocar placement for robot-assisted rectal anastomosis in pigs. C, Camera-trocar, umbilicus; R, right robot-arm trocar; L, left robot-arm trocar; A, assisting instruments.

Figure 2
Schematic overview of operating-theatre set-up during robot-assisted rectal anastomosis.
**Open surgical procedure: Control group**

These animals were positioned in a horizontal supine position. The rectum was exposed by a 20-cm midline incision. The mesocolon was dissected and the colon was divided by an identical stapling device as in the laparoscopic procedures. Approximation of proximal and distal parts as well as the anastomosis technique was identical to the laparoscopic procedure.

Conversions and complications were recorded in all groups. System set-up time was recorded in all robot-assisted cases. Total surgery time (skin-to-skin, not including system set-up time) and intraoperative blood loss were scored in robot-assisted group B only, because the animals in robot-assisted group A and the control group were also used for training involving other organ systems during the same session. Anastomosis time was scored in all groups. In robot-assisted group B, the postoperative course was evaluated, focusing on meals, stools, and complications. At autopsy the anastomosis and peritoneal cavity were explored. In all groups the number of stitches and the circumference of the anastomosis were recorded as well as the mean distance between stitches (circumference/number of stitches). The mechanical integrity of the anastomosis was evaluated by testing the bursting pressure. For this experiment, the anastomosis was connected to a pump and filled with water. A pressure canula was introduced in the intestinal lumen. Pressure was recorded until a sudden decline in the pressure curve was noted, followed by visible leakage. The highest measured pressure was recorded as the bursting pressure. All data were entered in SPSS and are expressed as median and range. Data were compared using the Mann–Whitney U-test, with significance at p values <0.05.
Results

All procedures in the robot-assisted groups could be completed laparoscopically. Intraoperative complications did not occur in robot-assisted group A and the control group. In robot-assisted group B, an assisting instrument caused an intestinal perforation while retracting the spiral colon. This perforation was closed with a Vicryl 4-0 suture and did not cause any problem during follow-up.

System set-up time mediated 14 min (range, 12–16). Total operative time (skin-to-skin) was 77 min (75–120) in robot-assisted group B. A constant operating time of 75 min was reached in the last 5 cases, after a learning curve of 15 cases (Figure 3).

Blood loss in this group comprised less than 10 ml in 9 cases and 100 ml in one. Anastomosis time was shorter in the control group than in the robot-assisted groups (10 min versus 33 min (group A) and 25 min (group B); p < 0.001; (Table 1). After a learning curve of 14 cases, a constant reproducible anastomosis time of 25 min or less was accomplished in the last six robot-assisted cases (Figure 4).

Postoperatively, all 10 pigs in group B had their first meal and stool on postoperative day 1. There were two complications. One animal suffered from a traumatic arthritis of the right lower knee joint, probably caused by fixing the limb to the OR table. The arthritis was treated by anti-inflammatory analgesics. Another pig suffered from an ileus with progressive abdominal distension. Spontaneous improvement was not to be expected after 6 days and the animal was terminated for autopsy.
at that time. The ileus was caused by herniation of the spiral colon through an abdominal wall defect at the point of the 12-mm help trocar insertion. There were no signs of leakage, (micro) abscesses, or peritonitis in any pig. In eight out of 10 cases, there were loose adhesions with the overlying uterine adnex. These adhesions could be removed easily by careful manual manipulation.

The passage of the anastomosis was adequate in all groups, and no anastomotic narrowing was encountered. The number of stitches and the circumference of the anastomosis were higher in the control group than in robot-assisted group A (Table 1, p < 0.001). There was no difference in these parameters between the control group and robot-assisted group B. The distance between stitches did not differ between groups. Bursting-pressure tests showed no significant difference between robot-assisted group A and the control group (Table 1). In both groups, one burst occurred at a relatively low pressure (25 and 37 mmHg), at a point where the distance between two stitches was close to 1 cm. The location of burst (Table 2) was within 0.5 cm of the anastomosis in four cases in robot-assisted group A. In four cases it occurred at the staple closure and in another two at distance from suture lines. In the control group, the burst occurred at the anastomosis in six cases and at the staple closure in three. In robot-assisted group B, bursting pressure was 145 mm Hg (117–178), with four bursts at the anastomosis and six at locations remote from any suture.
Table 1  **Comparison between robot-assisted laparoscopic handsewn intestinal anastomoses (Groups A and B) and control anastomoses, performed through laparotomy.**

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Control</th>
<th>(A-Control)</th>
<th>(B-Control)</th>
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<tbody>
<tr>
<td><strong>Anastomosis</strong></td>
<td>33 (25-55)</td>
<td>25 (25-35)</td>
<td>10 (9-12)</td>
<td><strong>P&lt;0,001</strong></td>
<td><strong>P&lt;0,001</strong></td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Circumference</strong></td>
<td>8,5 (8-10)</td>
<td>11,7 (10-15)</td>
<td>13 (11,5-13,5)</td>
<td><strong>P&lt;0,001</strong></td>
<td>NS</td>
</tr>
<tr>
<td><strong>Number of Stitches</strong></td>
<td>17 (14-18)</td>
<td>18,5 (17-22)</td>
<td>22,5 (20-26)</td>
<td><strong>P&lt;0,001</strong></td>
<td>NS</td>
</tr>
<tr>
<td><strong>Distance between Stitches</strong></td>
<td>0,53 (0,47-0,61)</td>
<td>0,62 (0,48-0,88)</td>
<td>0,55 (0,50-0,61)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Burst Pressure</strong></td>
<td>65 (25-125)</td>
<td>145 (117-178)</td>
<td>70 (37-123)</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 2  **Bursting-pressure in mmHg and site of bursting: 1: Within 0,5 cm distance from the anastomosis 2: Staples 3: Other location.**

<table>
<thead>
<tr>
<th>Case No</th>
<th>Group A</th>
<th>Group B</th>
<th>Control</th>
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<td></td>
<td>Burst</td>
<td>Location</td>
<td>Burst</td>
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<td>1</td>
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<tr>
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<tr>
<td>10</td>
<td>55,00</td>
<td>2</td>
<td>178,00</td>
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Discussion

Robotic systems for videoscopic surgery were introduced in the late 1990s to enhance manoeuvrability, visualisation, and ergonomics for minimally invasive thoracoscopic and laparoscopic surgery. Endoscopic beating-heart surgery was the initial field of interest because the technical challenge of this procedure surpassed the reach of traditional videoscopic techniques. During the past 2 years interest has expanded to laparoscopic surgery.

Although surgeons working with these systems express enthusiasm for the gain in control and visualisation, the imminent advantages of robotic systems in abdominal surgery are less apparent compared to cardiac surgery. Therefore, statistical proof of its merits will be hard to get in the short term, within the spectrum of well-documented routine laparoscopic interventions. Robotic surgery systems may prove to be excellent tools for routine videoscopic surgery in the future, but comparison to state-of-the-art equipment will be disappointing because of ergonomic issues in the current OR design and practical shortcomings of first-generation robotic systems. At this point, the subjectively apparent advantages of robotic surgery systems will therefore have to be proven by facilitating or supporting advanced laparoscopic interventions, such as procedures requiring suturing and knot tying.

Gastrointestinal hand-sewn videoscopic anastomosis is still regarded as a challenging manoeuvre. Stapling devices can deal with a large number of laparoscopic anastomosis, but interventions such as gastroenterostomy and bilio- or pancreatico-intestinal anastomosis still require videoscopic suturing and knot tying. Additionally, the hand-sewn robot-assisted anastomosis technique can be used at locations that are difficult to reach for endoscopic stapling devices.

Robot-assisted laparoscopic suturing has recently been introduced in various procedures, with promising initial experience. We chose a rectal side-to-side anastomosis in a pig model to demonstrate technical feasibility and safety of a complete laparoscopic sutured intestinal anastomosis with the help of the robotic system.

The complications that were encountered are directly related to videoscopic techniques, but could not be attributed to the use of the robotic system. The absence of signs of leakage of the anastomosis at autopsy supported the feasibility of performing a safe intestinal anastomosis in the pig (Group B). The technical quality of the laparoscopic anastomosis was further demonstrated by the results of the comparison of robotic group A to the control group when measuring the bursting pressure. This measurement is often used in experiments when evaluating anastomotic healing but was used in this experience to assess the technical correctness of the anastomosis. Although the bursting pressure could not be compared to a control group in group B, it revealed no mechanical failures and showed an expected trend toward a higher bursting pressure, after a period of anastomotic healing. The finding of adequate passage through the anastomosis, without strictures in all cases, and a constant distance between stitches further supported feasibility and efficacy. Although the use of a robotic surgery system for laparoscopic intestinal suturing has
been proven feasible in a pig model, its true value is yet to be proven in clinical practice.

Apart from proving safety and efficiency, data were gathered to find support for the additional value of robotics in advanced laparoscopic surgery. The relatively short anastomosis time might express these advantages. Although it took longer in the laparoscopic groups than in open surgery, the reproducible time of 25 min in the last five pigs (group B) appears promising to the authors. This mean anastomosis time was established after a relatively short learning curve of 14 cases (Fig. 5). These data support our sense of the ease of adaptation to robotic techniques in videoscopic surgery. A laparoscopic control group was not included in this feasibility study, but when evaluating the anastomosis time in comparison to the results of other experiments on laparoscopic intestinal anastomosis, the time needed for the robot-assisted running suture compares favourably to time needed for laparoscopic hand-sewn intestinal anastomosis by standard instruments. Standard laparoscopic suturing time is documented to be approximately 90 min \(^{30-33}\), more than three times the time required for anastomosis in this experiment. The total operating time showed an identical short learning curve (Fig. 4). System set-up time was not included in this operating time. The median set-up time found in this study was comparable to results of clinical research. We reported earlier on a reproducible set-up time of 15 min or less that can be obtained after a learning period of approximately 10 cases \(^{34}\).

When looking at future developments with special regard to training, robot-assisted surgery might offer potential benefits in decreasing learning curves and increasing safety in a teaching environment. Virtual reality training programs will be integrated in the robotic system computers. This will diminish the gap between surgical simulation environments and actual surgery. After successful completion of computer-aided training programs, future residents can be supported during initial clinical experience by coupling two consoles of the robotic surgery system. This allows the tutor to take over at any desired moment, or to literally take the resident by the hand to guide him or her in videoscopic manoeuvres.

These advantages result from the concept of telesurgery, where the first surgeon no longer joins the team at the OR table and where advanced computer technology is used to enhance vision and manoeuvrability. Recent experiments have demonstrated the feasibility of performing videoscopic surgery from beyond the OR theatre to even another continent, which brings the technical options of distant expert support within reach \(^{35,36}\).

In conclusion, this study demonstrated the feasibility of hand-sewn laparoscopic intestinal anastomosis with the use of a robotic system. Under circumstances where laparoscopic surgery becomes very challenging with traditional four-degrees-of-freedom instruments, the equipment is expected to be of significant support. Continuing research will therefore focus on proving advantages in technically challenging procedures, such as biliodigestive and vascular anastomosis.
References


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