Transrectal robotic natural orifice translumenal endoscopic surgery (NOTES) applied to intestinal anastomosis in a porcine intestine model

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Transrectal Robotic NOTES (Natural Orifice Translumenal Endoscopic surgery) applied to intestinal anastomosis in a porcine intestine model

Running head: Transrectal Robotic NOTES model

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Abstract

Background Natural orifice translumenal endoscopic surgery (NOTES) is a minimally invasive surgery using devices such as flexible endoscopes and linear or circular staplers. Nevertheless, hand-sewn anastomosis in NOTES remains challenging. We aimed to investigate the feasibility of transrectal robotic NOTES requiring intracorporeal small intestinal anastomosis and closure of the rectal anterior wall incision in a relevant human model.

Methods We developed a 43-mm diameter flexible rectal proctoscope for transrectal robotic NOTES. Small intestinal anastomosis was performed in a porcine intestinal transrectal NOTES model using two robotic arms and a camera inserted through the proctoscope and a rectal anterior wall incision. The quality of transrectal small intestinal anastomosis using the da Vinci surgical system (transrectal robotic NOTES group) was compared with that of transabdominal anastomosis using the da Vinci surgical system (transabdominal robot-assisted surgery group) and that of transrectal anastomosis using traditional Transanal Endoscopic Microsurgery (TEM) instruments (TEM NOTES group). The quality of transrectal rectal anterior wall suturing in the transrectal robotic NOTES group was compared with that of the TEM NOTES group and that using open surgical instruments (Open group).

Results We successfully performed robotic intracorporeal suturing in our porcine intestine model. During small intestinal anastomosis, burst pressure in the transrectal robotic NOTES group was similar to that in the transabdominal robot-assisted surgery group (67.7 ± 29.3 *vs.* 73.3 ± 18.2 mm Hg, respectively), but significantly higher than that in the TEM NOTES group (67.7 ± 29.3 *vs.* 20.3 ± 24.0 mm Hg; $p < 0.01$). During rectal anterior wall suturing, burst pressure was not significantly different between the transrectal robotic NOTES and the open group (149.9 ± 81.1 *vs.* 195.0 ± 60.5 mm Hg).

Conclusions We established the preliminary safety and efficacy of transrectal robotic NOTES. Further studies are required to determine the practical feasibility of this procedure.

Keywords NOTES • Robotic surgery • Transrectal • Anastomosis

Introduction

Natural orifice translumenal endoscopic surgery (NOTES) is a minimally invasive surgical procedure [1]. NOTES avoids incisions in the abdominal wall, and theoretically provides patient benefits by minimizing tissue trauma, postoperative pain, and potential wound complications [2]. Clinically, NOTES has been used for appendectomy, cholecystectomy, partial gastrectomy, and hybrid NOTES colectomy [3–8]. Experimental gastrointestinal tract surgery on swine and cadavers has also been performed [9]. Most gastrointestinal tract surgeries with NOTES are conducted with automatic anastomosis or suture instruments, and there are numerous reports on the development and use of specialized robots designed to perform surgery requiring a high degree of freedom such as intraperitoneal suturing conducted during NOTES [10–15].

The da Vinci Surgical system uses articulating laparoscopic instruments with wrist motion, and is particularly useful during suturing and knot tying [16, 17]. However, reports of robotic NOTES using the da Vinci Surgical system are rare as the surgical port is limited to the umbilicus, rectum, and vagina in such procedures [18, 19]. Using the da Vinci Surgical system with transrectal robotic NOTES allows surgery that requires a high degree of freedom such as intraperitoneal suturing.

In transrectal robotic NOTES, two robotic arms and one camera are inserted transrectally. This procedure is possible if a proctoscope with a slightly larger diameter and flexibility is used instead of the proctoscope typically used in Transanal Endoscopic Microsurgery (TEM). In addition, the anterior rectal wall must be securely sutured postoperatively as the surgical device is inserted intraperitoneally through a comparatively large incision in the anterior rectal wall during transrectal robotic NOTES. The aim of the present study was to examine the efficacy of robot-assisted suturing under a limited degree of freedom using two robotic instruments and a scope inserted from the rectum through the new proctoscope, and to assess the feasibility of secure closure of the rectal anterior wall incision in transrectal robotic NOTES using the da Vinci surgical system in a porcine intestine model.

Materials and Methods

Study design

This study used porcine viscera to assess the feasibility of transrectal robotic NOTES. We compared the quality of small intestinal anastomosis in three groups to evaluate the effectiveness of intraperitoneal surgical operations using transrectal robotic NOTES. The three groups were the transrectal robotic NOTES group, the transabdominal robot-assisted surgery group, and the TEM NOTES group. The error actions in the procedures used for the three groups were also compared to evaluate the intraperitoneal surgical operability. In addition, rectal wall suturing within each of the three groups was compared to confirm the efficacy of the suturing operations of the rectal anterior wall using transrectal robotic NOTES. The number of experiments was 12 in each group.

All of the procedures were performed by one surgeon (YD) with the following experience: advanced general surgery, intermediate level laparoscopic surgery, novice level experimental robotic surgery with experience in suturing only, within the experiments of this study (no clinical robotic surgery), and clinically experienced in TEM surgery but at a lesser level.

Transrectal NOTES model

A Tuebingen MIC trainer (Richard Wolf GmbH, Knittlingen, Germany) was set on an operating table of adjustable height and angulation (15°) in the Trendelenburg position. Two segments (15–20 cm) from the small bowel and one segment (20 cm) from the rectum were collected from adult pigs (50–60 kg). The pigs were cared for according to the “Guidelines for the Care and Use of Laboratory Animals” at the Takaramachi Campus of Kanazawa University. The small bowel segments were fixed at the base and middle of the Tuebingen MIC trainer 19 cm from the anal ring. One segment of the rectum (20 cm) was fixed around the anal ring where small intestinal anastomosis and suturing of the anterior rectum were performed. Because the pelvis of the MIC trainer mimics that of humans, TEM could be performed in a realistic anatomical simulation.

Flexible proctoscope device for transrectal robotic NOTES

Instead of a hard steel TEM proctoscope, we used a flexible flat-ended polycarbonate proctoscope (43 mm diameter, 12–16 cm length), which was purpose-built in our institution; therefore, there are no previous clinical data on this device. This proctoscope was inserted from the anal ring to the fixed porcine rectum in the Tuebingen MIC trainer. We recommend a 43 mm minimum diameter for the rectal scope used for transrectal robotic NOTES because this allows horizontal insertion of the two arms and the endoscopic camera of the da Vinci surgical system.

Small intestinal anastomosis

The technique used for intestinal anastomosis was the same in the transrectal robotic NOTES group, the transabdominal robot-assisted surgery group, and the TEM NOTES group, and involved side-to-side craniocaudal anastomosis with two single-layer continuous full-thickness 16 cm long sutures (3-0 Vicryl, Ethicon GmbH, Norderstedt, Germany) at the posterior and anterior walls. The surgeon began by suturing the 3 cm antimesenteric small intestinal wall incision of the previously severed small intestine, and the anastomosis was performed by tying the first craniad knot, closing the posterior wall with 3-0 Vicryl running suture, tying a second craniad knot, closing the anterior wall with another running suture (3-0 Vicryl), and finally tying the caudal knot. In cases of suture breakage or needle detachment, the participant was provided with an additional suture that was then tied to the original suture.

Small intestinal anastomosis in the transrectal robotic NOTES group

The da Vinci surgical system was positioned at the right side of the training box for this procedure

(Figure 1), and the motion-scaling system was set at 2:1 (normal mode). The robot was used in the transrectal robotic NOTES group and the small intestines were operated in the Tuebingen MIC trainer through the anterior rectal wall orifice (Figure 2). Two 8 mm robotic arms were inserted through the flexible scope and placed horizontally and symmetrically to the right and left, and a 12 mm camera was inserted through the flexible scope and placed above the two arms. An EndoWrist large needle driver (Intuitive Surgical, Sunnyvale, CA, USA) was chosen for the right arm, and EndoWrist Cadiere forceps (Intuitive Surgical) were chosen for the left arm.

Small intestinal anastomosis in the transabdominal robot-assisted surgery group

The da Vinci surgical system was used in the transabdominal robot-assisted surgery group and the small intestines were operated within the Tuebingen MIC trainer. Two 8 mm trocars for the robotic arms were placed symmetrically to the right and left. A 12 mm trocar for the camera was placed above the small intestine. An EndoWrist large needle driver was chosen for the right arm, and EndoWrist Cadiere forceps were chosen for the left arm. The robot was positioned at the right side of the training box for this procedure, and the motion-scaling system was set at 2:1 (normal mode).

Small intestinal anastomosis in the TEM NOTES group

In the TEM NOTES group, the small intestines were operated upon using the same settings as for the transrectal robotic NOTES group. The rectum accommodated the 4 cm-diameter operating TEM proctoscope, and allowed an insertion high enough for the rigid operating instruments to reach up and over the sacral promontory. The 12 cm, flat-ended TEM proctoscope was then inserted. A modified video TEM instrumentation was used, as well as a standard endoscopic needle holder, forceps, and 30° downward-facing two-dimensional camera (Karl Storz, Tuttlingen, Germany). The camera was fixed in a passive camera holder according to the preferences of the surgeon. Knot tying was performed in the training box.

Rectal anterior wall suturing

In both the transrectal robotic NOTES and TEM NOTES groups, the same technique was used for suturing the 5 cm incision of the anterior rectal wall, and involved a single-layer of full-thickness interrupted sutures (3-0 Vicryl sutures).

Rectal anterior wall suturing in the transrectal robotic NOTES group

The da Vinci surgical system was used in the robot-assisted group. Two 8 mm robotic arms were inserted through the flexible proctoscope and placed horizontally and symmetrically to the right and left. A 12 mm, 30° downward-facing camera was inserted through the flexible scope and was placed above the two arms. After the small intestinal anastomosis, the rectal anterior wall orifice was sutured in the surgical training box on the mucosal membrane side. The EndoWrist large needle driver was chosen for the right arm, and EndoWrist DeBakey forceps were chosen for the left arm. The motion-scaling system was set at 2:1 (normal mode) during this procedure.

Rectal anterior wall suturing in the TEM NOTES group

In the TEM NOTES group, the rectums were operated using the same settings as for the robot-assisted group. A standard endoscopic needle holder, forceps, and two-dimensional camera (Karl Storz) were used. The camera was fixed in a passive camera holder according to the surgeon's preference. Knot tying was performed outside the training box.

Rectal anterior wall suturing in the open surgery group

The open group formed the control group. The rectal anterior wall was sutured from the serosal membrane side.

Performance assessment

We measured the anastomosis duration, the time required for the entire suturing process, the number of stitches, the circumference of the anastomosis, and the mean distance between stitches to assess the anastomosis quality. In addition, we examined the line of anastomosis for macroscopically large gaps between stitches (a space of > 5 mm was considered large). The TEM anastomosis procedures were compared with anastomosis procedures performed with robot-assisted suturing in terms of anastomosis duration and quality.

Measurement of burst pressure during anastomosis and suturing

The mechanical integrity of the anastomosis and suturing was evaluated by determining the burst pressure. In this experiment, the small intestine or rectum was connected to a pump and filled with water, and a pressure cannula was introduced into the intestinal lumen. Pressure was recorded until a sudden decline in the pressure curve occurred followed by visible leakage. The highest measured pressure was recorded as the burst pressure.

Error action analysis

All anastomoses in the small intestine were recorded using a digital video recorder, and an error action analysis was then performed. We counted only predefined failure actions during suturing and knotting phases as established by Ruurda et al. [20]. The predefined errors were counted and evaluated independently in the three groups.

Statistical analysis

Data are expressed as mean ± standard deviation (SD), and the numbers of error actions were expressed as median and range. Continuous nonparametric data were compared using the Mann–Whitney U-test and categorical data using the chi-square test. A P-value less than 0.05 was considered statistically significant. Statistical analysis was performed with SPSS ver. 16.0 (SPSS Inc., Chicago, IL, USA).

Results

We successfully performed robotic intracorporeal suturing and knot tying using a Tuebingen MIC trainer in a porcine intestine model for transrectal robotic NOTES. All procedures in the robot-assisted groups were performed laparoscopically and the intraoperative results are shown in Table 1. Low burst pressure (< 20 mm Hg) occurred in only one experiment (No. 3) in the robotic NOTES group. This was not observed in later experiments in this group and likely reflects the learning curve. The mean burst pressures in the transrectal robotic NOTES group (67.7 ± 29.3 mm Hg) and the transabdominal robotic group (73.3 ± 18.2 mm Hg) were significantly higher than that in the TEM NOTES group (20.3 ± 24.0 mm Hg, $p < 0.01$); there were no differences between the robotic NOTES group and the transabdominal robotic group. The mean anastomosis duration was shorter in the robotic NOTES group (35.3 ± 10.8 min) than in the TEM NOTES group (58.1 ± 5.6 min, $p < 0.01$), but longer in the robotic NOTES group than in the transabdominal robotic group (24.8 ± 4.1, $p < 0.01$). The number of stitches did not differ significantly between the three groups. The mean circumference was larger in the transrectal robotic NOTES group (71.9 ± 7.2 mm) than in the TEM NOTES group (49.6 ± 8.2 mm) ($p < 0.01$). There was no difference in the mean circumference between the robotic NOTES group and the transabdominal robotic group (69.2 ± 9.6 mm). The number of cases in which the distance between the stitches was greater than 5 mm was 1 (8.3%) in the transabdominal robotic group and 4 (33.3%) in the TEM NOTES group; however, there were no significant differences between the three groups. The location of the burst site was not significantly different between the three groups.

The results of the error action analysis are shown in Table 2. There were no significant differences in the total number of failures in the stitching and knot tying phases between the transrectal robotic NOTES group and the transabdominal robotic group, while more failures were observed in the TEM NOTES group than in the other groups. The quality and ease of performance of intracorporeal small intestinal anastomosis was not significantly different between the transrectal robotic NOTES group and the transabdominal robotic group.

The results of the comparison of secure closure of the anterior rectal wall incision after transrectal NOTES and rectal wall suturing between the robotic NOTES, TEM NOTES, and control groups are shown in Table 3. During rectal anterior wall suturing, the mean burst pressure was not significantly different between the TEM NOTES group (95.5 ± 43.5 mm Hg) and the robotic NOTES group (149.9 ± 81.1 mm Hg) and between the robotic NOTES group and the control group (195.0 ± 60.5 mm Hg). Suture duration was shorter in the robotic NOTES group (18.7 ± 3.7 min) than in the TEM NOTES group (25.2 ± 1.6 min) ($p < 0.01$), but longer in the robotic NOTES group than in the control group (5.9 ± 0.8 min) ($p < 0.01$). The number of stitches did not differ significantly between the three groups.

The learning curve for the transrectal NOTES procedure diminished quickly compared with that for TEM when performing the anastomosis, with the results in the first half of the experiments markedly different than those in the latter half. The learning curve for anastomosis in the TEM experiments did not diminish over the course of the 12 experiments but did diminish for the error actions. The learning curve of the error actions changed very little using the transabdominal robotic procedure and the overall operability of transrectal NOTES was similar to the transabdominal robotic procedure. The results of the learning curves are shown in Figure 3 and 4.

Discussion

This study describes the feasibility and usefulness of transrectal robotic NOTES using the da Vinci surgical system. The three major findings of our study were: (1) anastomotic operation of the small intestine was possible in a transrectal model using the da Vinci surgical system; (2) for intraperitoneal small intestinal anastomosis, the operability for anastomosis and the quality of anastomosis by transrectal robotic NOTES were superior to anastomosis with laparoscopic forceps, and were comparable to transabdominal robotic anastomosis; and (3) the transrectal robotic NOTES technique resulting in suturing the anterior rectal wall as effectively as open suture.

In intraperitoneal small intestinal anastomosis, the operability for anastomosis and the quality of anastomosis by transrectal robotic NOTES were superior to anastomosis with laparoscopic forceps, and were comparable to transabdominal robotic anastomosis. To our knowledge, there are no reports of intraperitoneal hand-sewn anastomotic operations being performed using robots or forceps for transrectal NOTES. Anastomosis performed by a robot in laparoscopic surgeries is generally superior to those performed by forceps, particularly in transrectal cases [16, 17, 19], as a favorable operative field can be obtained by three-dimensional imaging with high resolution in the robot group. Furthermore, using an EndoWrist instrument, needle handling is accurate and fine, and the da Vinci surgical system can allow stable handling of the needle even under poor arm conditions. The motion and operability of the laparoscopic forceps in transrectal NOTES are similar to those of single-port surgery. There are only a small number of reports of single-port surgeries where the port is set in the umbilicus and the clinical usefulness has been assessed [21]. Also, there are no reports of motion and operability of the laparoscopic forceps in single-port surgery. However, this is not a surgery that requires a high degree of freedom, but only an extraction of minor organs [22, 23]. There is also only one report showing that anastomosis performed by a robot is superior to anastomosis by forceps when Nissen fundoplication is performed in a single-port surgery where the port is set in the umbilicus [24]. Anastomosis with forceps is technically difficult and unrealistic in transrectal NOTES. In our study, anastomosis in a single-port surgery using forceps was very complicated, techniques repeated several times were not stable, and anastomosis time was not shortened. In contrast, techniques and in the robot stabilized after only a small number of trials.

The number of error actions also reflects the operability of laparoscopic surgical procedures such as conventional laparoscopic instruments and other new laparoscopic surgical devices [25]. We found no significant differences in the total number of failures in the stitching and knot tying phases between the transabdominal robotic group and the robotic NOTES group, while more failures were observed in the TEM NOTES group than in the other groups. The advantages of the transrectal robotic NOTES were observed during all phases of suturing, as the da Vinci surgical system provides stable handling of the needle. The main technological advantages of this system include a true three-dimensional endoscope that provides a high-resolution binocular view of the surgical field, an EndoWrist instrument system capable of 7 degrees of freedom and 2 degrees of axial rotation to replicate human wrist-like movements and tremor filtration, and motion-scaling systems to enhance surgical dexterity.

The transrectal robotic NOTES procedure allowed suturing of the anterior rectal wall with equal efficacy to open suture. Transrectal robotic NOTES requires a large incision in the anterior rectal wall for insertion of the two arms and one camera, as well as for closure by complete suture. We were able to suture the anterior rectal wall transrectally under a burst pressure equal to that with open suture. Moreover, the pressure after suturing in the rectum was 149.9 ± 81.1 mm Hg, which is comparable to reports examining other rectal suturing techniques [16, 25], and equivalent to the maximal squeeze pressure (MSP) of anorectal manometric values after TEM surgery [26]. There was no difference in the burst pressure between the TEM NOTES group and the robotic NOTES group, and the suture duration was shorter in the robotic NOTES group than in the TEM NOTES group. Diana et al. reported the feasibility of a transrectal viscerotomy closure with suturing using a TEM platform and a circular stapling technique [27]. Transrectal direct suture using a robot is a useful method for route closure in transrectal NOTES.

There are two advantages of robotic NOTES using the da Vinci surgical system compared with NOTES using other newly-developed robotic devices [10–15]. First, the range of motion of the arm is wide. To perform some operations, particularly anastomotic operations, a relatively wide range of motion of the right and left arm is required, otherwise the operability decreases dramatically. Next, the position of the right and left arms is stable. A potential limitation of NOTES is that grasping the relative position between the endoscope and the arms can be difficult, whereas grasping the relative position between the camera and arms is simple in the da Vinci surgical system.

In our experiments, the Tuebinger MIC-Trainer was used instead of a pig. The anatomical differences between humans and pigs can be a major problem when investigating transrectal robotic NOTES [28]. The Tuebinger MIC-trainer allows surgeons to perform basic experimental surgery under anatomical conditions similar to that of the human body and the MIC trainer is currently used in every training course for basic and advanced laparoscopic surgery at the Tuebingen University. The design of the base of the trainer has an anatomical shape similar to that of the posterior wall of the human abdominal and pelvic cavity.

Transrectal robotic NOTES requires insertion of two arms and a camera scope. A typical TEM scope is made of steel and has no flexibility, making it impossible to insert two arms and one camera. However, transrectal robotic NOTES is considered feasible when the diameter of the scope is slightly larger and the scope is retractable and flexible. We used a flexible 43 mm diameter scope as a rectal proctoscope. This system may be feasible for use in the clinical setting.

The usual proctoscope diameter for TEM is 40 mm and because even this diameter is associated with transient fecal incontinence, there is concern about the increased diameter of our proctoscope. Clinical trials are needed to determine if the 3-mm increase in scope diameter will have the same or worsened effect.

The surgical position in the transrectal robotic NOTES may be limited. Separate insertion of the arms and camera as for procedures on the upper body, is not possible via the anus. Therefore, there is little freedom in the arm setting, and the body of the robot and upper body of the patient interfere with each other during the procedure. The use of the da Vinci surgical system for clinical transanal resection of a tumor in the rectum was previously reported [29], and surgery was possible by offsetting the upper body of the patient to the right side of the robot’s body. Similarly, in the present study the operation was possible by offsetting the model diagonally and performing the procedures in the Trendelenburg position, which is practical in a clinical setting.

To model conditions in humans, we used porcine intestinal tract to perform the anastomosis. As previously reported, fresh porcine intestines can be used to assess the quality of the anastomosis using the burst pressure [16, 24, 30]. Fresh intestine is preferable to assess the quality of the anastomosis.

Pneumoperitoneum was not assessed in the present study. However, in typical transrectal NOTES, sealing the bottom of the TEM scope and insufflating with air from the side hole of the TEM scope can promote pneumoperitoneum [28]. Establishing pneumoperitoneum is possible using a similar method in transrectal robotic NOTES.

In summary, we report the preliminary feasibility of transrectal robotic NOTES in a human-shaped model using a porcine intestine model. Because of the evolution of the da Vinci surgical system there will be ongoing improvements in the range of the surgical arms, the features of the proctoscope, and the body position, which will improve the applicability of this technique. Using a flexible endoscope instead of the da Vinci surgical system endoscopic camera can reduce operability, but improves the visual field during surgery. Further studies, under similar clinical conditions using either improved models or vivisection employing pigs, are required.

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Disclosures

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Figure legends

Figure 1. Position of the da Vinci surgical system.

Figure 2. The small intestines were operated in the Tuebingen MIC trainer through the anterior rectal wall orifice.

Figure 3. Learning curve for anastomosis time for the different procedures in small intestinal anastomosis.

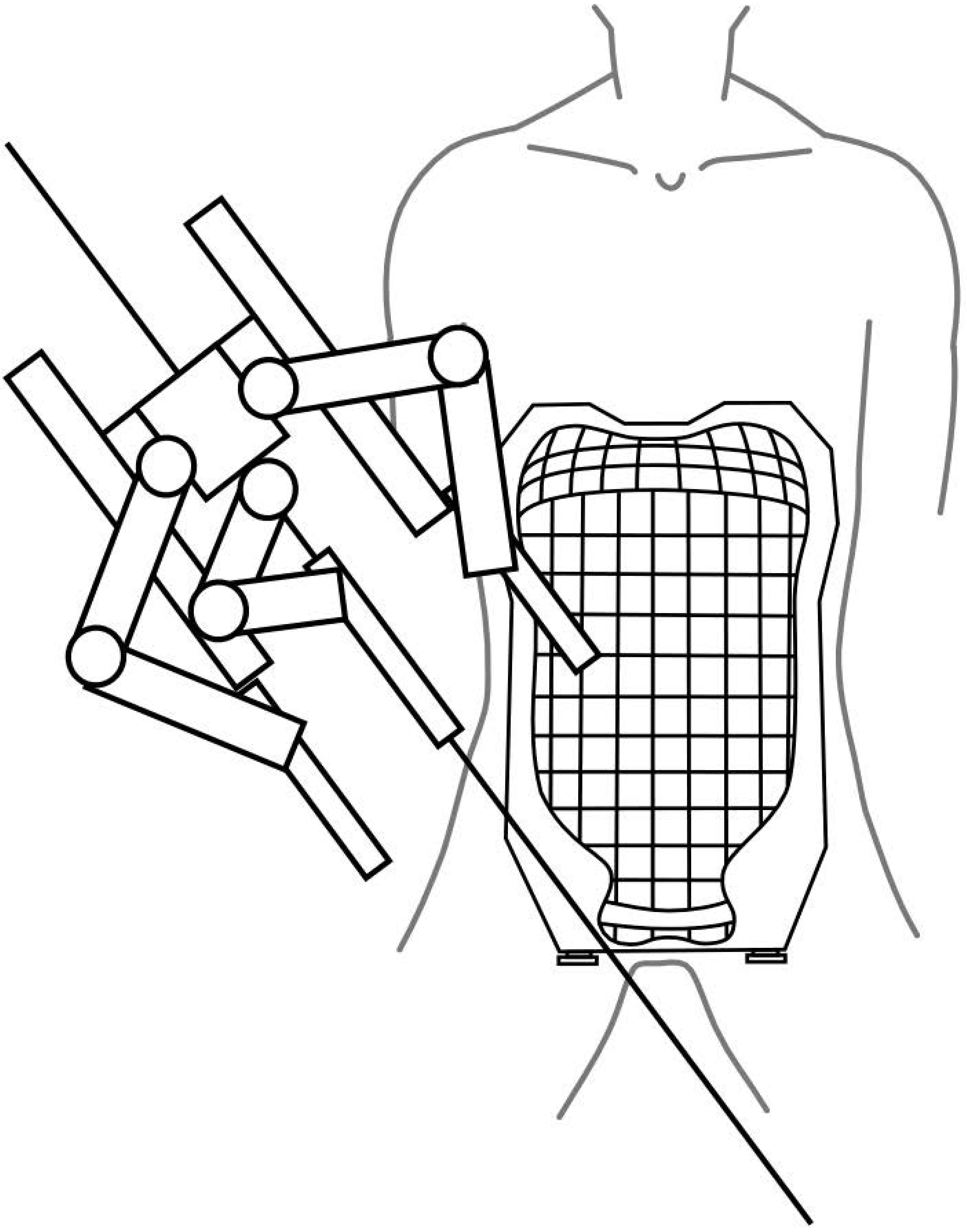
Figure 4. Learning curve for number of error actions for the different procedures in small intestinal anastomosis.

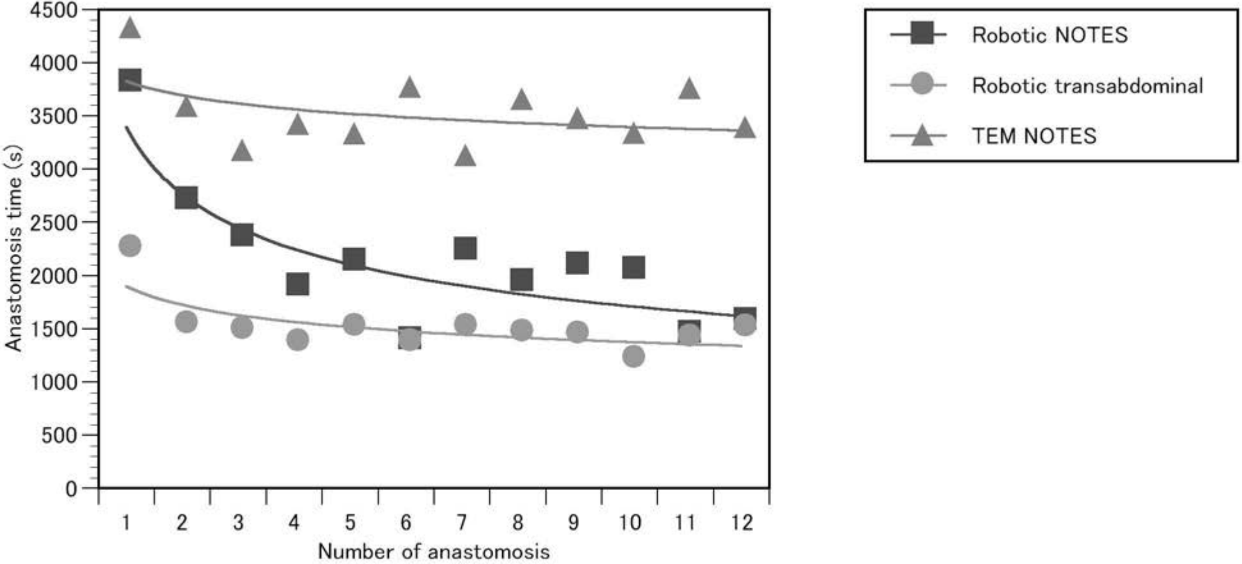
Tables

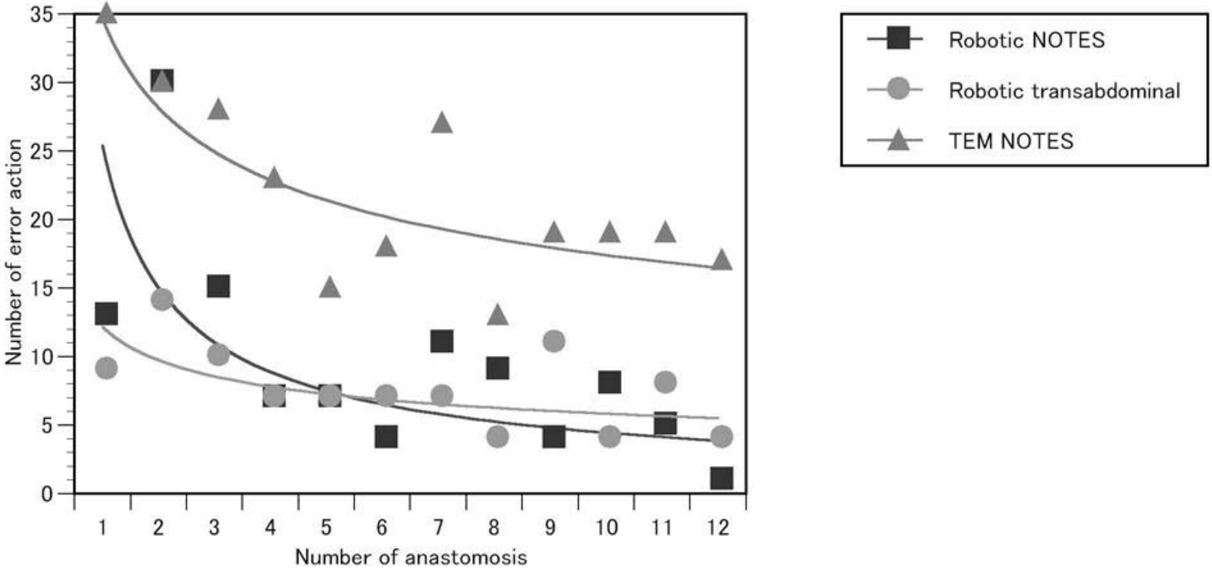
Table 1. Comparison between robot-assisted transabdominal intestinal anastomosis and robot-assisted NOTES anastomosis and NOTES anastomosis using the TEM device and technique.

Table 2. Results of the error action analysis.

Table 3. Comparison between robot-assisted transanal rectal anterior wall closure, TEM closure, and open closure.




4500
4000
3500
3000
2500
2000
1500
1000
500
0
Anastomosis time (s)
1
2
3
4
5
6
7
8
9
10
11
12
Number of anastomosis
Robotic NOTES
Robotic transabdominal
TEM NOTES



Robotic NOTES
Robotic transabdominal
TEM NOTES
Number of error action
Number of anastomosis
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
8
9
10
11
12

Table 1. Comparison between robot-assisted transabdominal intestinal anastomosis and robot-assisted NOTES anastomosis and NOTES anastomosis using the TEM device and technique

	Robotic transabdominal	Robotic NOTES	TEM NOTES	p-value	
				Robotic transabdominal *vs.* Robotic NOTES	Robotic NOTES *vs.* TEM NOTES
Burst pressure (mm Hg)	73.3±18.2	67.7±29.3	20.3±24.0	n.s.	0.0008
Anastomosis time (min)	24.8±4.1	35.3±10.8	58.1±5.6	0.0047	0.0004
Number of stitches	23.2±4.5	21.3±2.6	19.5±3.3	n.s.	n.s.
Circumference (mm)	69.2±9.6	71.9±7.2	49.6±8.2	n.s.	0.0001
Distance between stitches > 5 mm				n.s.	n.s.
0	11/12 (91.7%)	12/12 (100%)	8/12 (66.7%)		
×1	1/12 (8.3%)	0/12 (0%)	2/12 (16.7%)		
×2	0/12 (0%)	0/12 (0%)	2/12 (16.7%)		
Burst site				n.s.	n.s.
Cranial edge	4/12 (33.3%)	1/12 (8.3%)	3/12 (25.0%)		
Running suture	8/12 (66.7%)	11/12 (91.7%)	7/12 (58.3%)		
Caudal edge	0/12 (0%)	0/12 (0%)	2/12 (16.7%)		

n.s., not significant (n=12)

Table 2. Results of the error action analysis

Error actions	Robotic transabdominal	Robotic NOTES	TEM NOTES	p-value	
				Robotic transabdominal *vs.* Robotic NOTES	Robotic NOTES *vs.* TEM NOTES
Stitching phase					
Failure to grasp the needle	0 (0–0)	0 (0–0)	0.3 (0–3)	n.s.	n.s.
Failure to grasp the tissue	0 (0–0)	0.1 (0–1)	1.8 (0–7)	n.s.	0.0009
Failure to enter the needle	0.8 (0–3)	1.6 (0–7)	5.4 (3–9)	n.s.	0.0007
Failure to exit the needle	0 (0–0)	0.3 (0–2)	0.5 (0–1)	n.s.	n.s.
Total failed actions in the stitching phase	0.8 (0–3)	1.9 (0–7)	7.9 (5–12)	n.s.	0.0003
Knot phase					
Failure to grasp the wire	3.2 (1–8)	2.6 (0–5)	5.0 (1-–2)	n.s.	n.s.
Failure to loop	2.4 (0–7)	4.0 (1–20)	5.9 (2–18)	n.s.	n.s.
Failure to pull through	0.8 (0–2)	0.6 (0–2)	1.8 (0–3)	n.s.	0.0114
Total failed actions in the knot phase	7.2 (4–10)	6.4 (1–24)	12.7 (5–26)	n.s.	0.0083
Both phases					
Needle drops	0 (0–0)	0.1(0–1)	1.3 (0–3)	n.s.	0.0078
Thread breaks	0.6 (0–2)	0.3 (0–2)	0 (0–0)	n.s.	n.s.
Total failed actions in both phases	7.7 (4–14)	9.5 (1–30)	21.9 (13–35)	n.s.	0.0006

n.s., not significant (n=12)

Table 3. Comparison between robot-assisted transanal rectal anterior wall closure, TEM closure, and open closure

	TEM NOTES	Robotic NOTES	Open	p-value	
				TEM NOTES *vs.* Robotic NOTES	Robotic NOTES *vs.* Open
Burst pressure (mm Hg)	95.5±43.5	149.9±81.1	195.0±60.5	n.s.	n.s.
Anastomosis time (min)	25.2±1.6	18.7±3.7	5.9±0.8	0.0005	0.0000
Number of stitches	10.5±1.6	11.3±0.8	11.3±0.5	n.s.	n.s.

n.s., not significant (n=12).