

Transgastric Natural Orifice Transluminal Endoscopic Surgery for Adhesiolysis: A Study in a Beagle Model of Adhesive Intestinal Obstruction

Wen Lin

Fujian Medical University

Chuan-Shen Jiang

Fujian Medical University

Xin-Yi Zheng

Fujian Medical University

Dong-Gui Hong

Fujian Medical University

Long-Ping Chen

Fujian Medical University

Yan Zhuang

Fujian Medical University

Han Lin

Fujian Medical University

Wen Wang

Fujian Medical University

Xiao-Jian He

Fujian Medical University

Da-Zhou Li

Ldz7302999@sina.com

Fujian Medical University

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Abstract

Background and aims

Adhesiolysis is the definitive treatment for adhesive intestinal obstruction (AIO), yet conventional open or laparoscopic approaches result in abdominal surgical scars and are associated with relatively high recurrence rates. This study aimed to evaluate the feasibility, safety and efficacy of transgastric natural orifice transluminal endoscopic surgery (TG-NOTES) for adhesiolysis in a beagle model of AIO.

Methods

Ten healthy beagles (1–2 years old, 10–13 kg) were used to establish an AIO model via serosal abrasion and chemical stimulation. Two weeks post-modeling, TG-NOTES adhesiolysis was performed under gastroscopic guidance. Intraoperative parameters (adhesiolysis duration, vital signs, blood loss) and intra-/postoperative complications were recorded systematically. All beagles underwent gastroscopic re-examination at 6 months postoperatively to assess gastric wall wound healing, followed by exploratory laparotomy to detect intra-abdominal adhesion recurrence and infectious complications.

Results

AIO models (grade 1–3 according to the Bologna guidelines) were successfully established in all 10 beagles, and TG-NOTES adhesiolysis was technically successful in all cases. The mean adhesiolysis duration was (98.6 ± 8.47) minutes, with intraoperative blood loss < 20 mL in all animals. Vital signs remained stable intraoperatively, and no severe complications (massive hemorrhage, intestinal perforation, anesthetic accidents) were observed. All beagles survived the 6-month follow-up period without postoperative complications (incision infection, intra-abdominal infection, intestinal fistula). Gastrosocopy confirmed satisfactory gastric wall incision healing, and no recurrent adhesions or intra-abdominal infection were found during laparotomy. Postoperatively, all beagles showed normalized food intake, defecation and significant weight gain compared with the pre-operative period.

Conclusion

Preliminary experimental evidence indicates that TG-NOTES adhesiolysis is a safe and effective minimally invasive procedure for grade 1–3 AIO in beagles, with the advantages of scarlessness, minimal blood loss and low short-term complication rate. This technique holds promising potential as an innovative therapeutic option for AIO patients, especially those with high aesthetic demands, and provides a basis for subsequent clinical translation.

1. Introduction

Intestinal obstruction is one of the most prevalent gastrointestinal emergencies, causing significant suffering to patients. The most common cause of intestinal obstruction is adhesions, usually from previous abdominal surgery [1]. Many studies have recognized that a history of abdominal surgery is an important risk factor for recurrence of intestinal obstruction. More than 90% of patients who undergo intra-abdominal surgery will develop adhesions, and approximately 80% of patients with AIO have a history of intra-abdominal surgery [2].

Adhesiolysis is one of the most important and effective treatment options for AIO. Traditional laparotomy involves greater trauma, more bleeding, longer postoperative recovery time, and a higher incidence of incisional hernia [3]. Laparoscopic surgery is now considered an effective alternative when performed by experienced surgeons because it offers several advantages, such as reduced peritoneal injury, recurrence rate, and postoperative pain, as well as faster postoperative recovery [4]. Although laparoscopic technology can reduce tissue damage and peritoneal exposure to a certain extent compared with traditional laparotomy, postoperative adhesions remain a substantial burden [5]. Furthermore, laparoscopic surgery still requires multiple incisions in the abdominal wall, which will also leave scars on the body surface. With the further improvement of people's demand for beauty, the concept of minimally invasive surgery has been further refined and advanced. Recent guidelines from the World Association of Emergency Surgery suggest that minimally invasive approaches may be a safe and feasible alternative that may reduce the incidence of adhesions [6].

Natural orifice transluminal endoscopic surgery (NOTES) represents a revolutionary advancement in minimally invasive surgery, enabling surgical procedures exclusively through natural orifices (e.g. oral cavity, vagina, anus) without abdominal wall incisions [7]. Driven by advancements in optical imaging, materials science, and endoscopic instruments, techniques such as endoscopic mucosal resection, endoscopic submucosal dissection, and endoscopic full-thickness resection have expanded the scope of digestive endoscopy from diagnosis to minimally invasive therapy [8–9]. The maturity of these endoscopic technologies provides the equipment and operational basis for the development of NOTES. Current developments in digestive endoscopic minimally invasive techniques focus on enhancing surgical precision, safety, and treatment indications. Many gastrointestinal disorders previously requiring laparotomy are now manageable via endoscopic interventions, substantially improving patient prognosis and quality of life.

The safety and effectiveness of transumbilical endoscopic adhesiolysis have been verified [10]. However, this approach requires an umbilical puncture incision, limiting its applicability in patients with high aesthetic expectations. In contrast, transgastric NOTES (TG-NOTES), a major branch of NOTES, avoids any abdominal wall incision or puncture, achieving a truly scar-free outcome and thereby offering superior aesthetic benefits compared to the transumbilical approach [11]. The standard operative workflow involves inserting an endoscope through the oral cavity into the digestive tract, creating a puncture channel through the gastric wall to access the peritoneal cavity, and then proceeding with the intended surgical procedure. Aligned with the core concept of avoiding abdominal wall incisions, TG-NOTES represents a significant advancement toward the "scar-free" goal in minimally invasive surgery.

Tracing its developmental course, since Kalloo et al.[12] first successfully performed transgastric abdominal exploration in a porcine model in 2004, TG-NOTES has been successfully applied in cholecystectomy [13], peritoneal cyst resection [14], and abdominal foreign body removal [15–16].

Despite the promising potential of TG-NOTES, its safety and efficacy for AIO adhesiolysis have not been fully evaluated in animal models. The present study established a canine model of AIO and performed TG-NOTES adhesiolysis to evaluate its technical feasibility, safety and short-term efficacy. We aimed to develop a minimally invasive strategy integrating safety, efficacy and aesthetics, and provide experimental evidence for the subsequent clinical translation of TG-NOTES in the treatment of AIO.

2. Materials and methods

2.1 Surgical equipment

The instruments used in this study included gastric endoscope (GIF-Q260J; Olympus Optical Co., Ltd., Tokyo, Japan), dual knife (KD-650L; Olympus Medical Systems), hook knife (KD-620LR; Olympus Medical Systems), nano knife (KD-640LR; Olympus Medical Systems), transparent cap (D-201–11804; Olympus Medical Systems), hot biopsy forceps (FD-410LR; Olympus Medical Systems), soft tissue clamp (ROCC-D-26-195; Nanwei Medical Technology Co., Ltd., Nanjing, China), high-frequency electrical equipment (VIO300D; ERBE Electronic Medical Instruments Co., Ltd., Tübingen, Germany)

2.2 Animals

Ten healthy beagles (age 1–2 years, weight 10-13kg) were obtained from the experimental animal center of our hospital. All experimental procedures were approved by the Ethics Committee of the 900th Hospital of PLA Joint Logistic Support Force (Approval ID: 2023-53) and complied with the Guide for the Care and Use of Laboratory Animals (8th edition, NIH). Prior to surgery, all beagles were fasted for 24 hours and deprived of water for 8 hours to empty the gastrointestinal tract. Anesthesia was induced by intramuscular injection of tiletamine hydrochloride and zolazepam hydrochloride (10 mg/kg) into the gluteal region. Anesthesia was confirmed by stable breathing, regular heart rate, and absence of response to noxious stimuli. Vital signs (heart rate, respiratory rate, blood pressure, SpO₂) were monitored continuously via electrocardiogram, and additional anesthetic agents were administered as needed based on intraoperative movement. All instruments were sterilized in compliance with the standard surgical asepsis protocols.

2.3 Establishment of animal models

The model was established based on previously described methods with improvements [17]. The beagles were placed in a supine position on the operating table, and routine skin preparation, disinfection, and draping were performed. The abdominal cavity was entered through a midline incision. 1–2 segments of the intestine were randomly selected and dragged out of the abdominal cavity to expose them to the air. Serosal layer on the surfaces were abraded with sterile gauze until loss of gloss and punctate hemorrhage occurred. A drop of anhydrous ethanol was applied to the abraded area to

further enhance adhesion formation (Fig. 1). The corresponding parietal peritoneum was then similarly abraded with sterile gauze to create an uneven wound surface between the organ and the peritoneum. Finally, the abdominal muscles and skin were closed with interrupted sutures.

2.4 TG-NOTES abdominal exploration and adhesiolysis

Beagles were acclimatized under standard conditions for 2 weeks and then underwent TG-NOTES abdominal exploration and adhesiolysis. Operators responsible for abdominal exploration and adhesiolysis were not involved in the modeling process to avoid bias. As shown in Fig. 2, the beagle under general anesthesia was placed on the operating table in the left lateral decubitus position. A mouth pad was placed, and the gastric cavity was irrigated with sterile water via a gastroscopy until free of food residues. 200 mL of chlorhexidine solution was instilled into the gastric cavity, maintained for 10 minutes before aspiration, followed by rinsing with normal saline. The optimal anterior gastric wall incision site was located using gastroscopic illumination and abdominal compression, and the gastric wall was fully incised using a dual knife or hook knife. Pneumoperitoneum was established with a CO₂ insufflator, and intra-abdominal pressure was maintained at about 8–10 mmHg with a laparoscopic pressure detector. The anterior abdominal wall was elevated to expose intra-abdominal organs. Laparoscopic exploration proceeded in the order of right lower, right upper, left upper, and left lower quadrants. The level of obstruction was identified by systematically tracing the dilated intestinal segment proximally to the point of transitional zone, where distinct adhesive bands were visualized. Adhesiolysis was conducted using a hook knife or nano knife. After that, the peritoneal cavity was irrigated with normal saline, and upon confirming no intra-abdominal hemorrhage or organ injury, the CO₂ was evacuated. The gastroscopy was withdrawn, and the gastrotomy incision was closed with soft tissue clamps.

2.5 Postoperative management

All beagles received a liquid diet within 24 hours postoperatively, with gradual transition to a normal diet. Intramuscular injection of cefazolin sodium was administered for 3 consecutive days to prevent infection. Gastroscopic re-examination was performed 6 months postoperatively to assess gastric wall incision healing. Exploratory laparotomy was then conducted to evaluate the abdominal cavity for the presence of adhesion recurrence and intra-abdominal infection.

2.6 Outcome measurement

The outcome measures included successful model establishment, technical success of TG-NOTES adhesiolysis, intraoperative parameters such as duration of adhesiolysis, blood loss, vital sign stability. Intraoperative blood loss was estimated as the volume of fluid in the suction canister minus the volume of irrigation fluid used. Intraoperative and postoperative complications, including intestinal perforation, organ damage, infection, and death, were monitored and recorded. Adhesion classification was performed strictly in accordance with the Bologna guidelines for the diagnosis and management of adhesive small bowel obstruction (Table 1) [6]. Adhesion severity was assessed in four abdominal

quadrants (right upper, right lower, left upper, left lower) independently. The highest grade observed in any quadrant was recorded as the overall grade for that animal. Outcomes further included postoperative general conditions (weight, activity, food intake, defecation), gastric wall incision healing and adhesion recurrence and intra-abdominal infection 6 months after surgery.

Table 1
Classification of adhesions according to the Bologna guidelines

Grade 0	No adhesions or insignificant adhesions
Grade 1	Adhesions that are filmy and easy to separate by blunt dissection
Grade 2	Adhesions where blunt dissection is possible but some sharp dissection necessary, beginning vascularization
Grade 3	Lysis of adhesions possible by sharp dissection only, clear vascularization
Grade 4	Lysis of adhesions possible by sharp dissection only, organs strongly attached with severe adhesions, damage of organs hardly preventable

3. Statistical analysis

SPSS 26.0 statistical software (SPSS, Inc., Chicago, IL) was used to analyze all the study data. Normally distributed measurement data were expressed as mean $\pm$ standard deviation ($\bar{x} \pm s$); non-normally distributed measurement data were expressed as median and interquartile range M (IQR), and count data were expressed as percentages. No statistical comparison was performed due to the single-arm study design.

4. Results

4.1 Modeling situation

AIO models were successfully established in all 10 beagles, with adhesion grades classified as grade 1 (n = 3), grade 2 (n = 4) and grade 3 (n = 3) according to the Bologna guidelines. Two weeks post-modeling, all beagles exhibited typical clinical manifestations of AIO, including reduced food intake (50–70% of the pre-modeling level), decreased defecation frequency (0–1 times/day vs. 2–3 times/day pre-modeling) and weight loss (1.2 ± 0.3 kg). Four beagles additionally presented with intermittent vomiting (1–2 times/day). Intraoperative exploration during TG-NOTES adhesiolysis confirmed intestinal dilatation and varying degrees of adhesions between the intestine tract and parietal peritoneum (n = 7) or between adjacent intestinal segments (n = 3) in all beagles.

4.2 Adhesiolysis conditions

Adhesiolysis was technically successful using TG-NOTES in all 10 beagles, with a success rate of 100%. The average time of adhesiolysis was (98.6 ± 8.47) minutes (range: 86–111 minutes), and the amount of

intraoperative blood loss was minimal (< 20 mL). During the operation, the animals' vital signs remained stable (heart rate: 80–105 beats/min, respiratory rate: 15–23 breaths/min, SpO₂: >95%), and no complications such as intestinal perforation, damage to abdominal organs, massive bleeding, and death occurred. The intra-abdominal pressure during pneumoperitoneum was maintained within the preset range of 8–10 mmHg.

4.3 Postoperative short-term outcomes

All 10 beagles survived the postoperative period without severe short-term complications. Postoperative vomiting resolved in all 4 affected beagles within 3 days postoperatively. All beagles resumed normal food intake and defecation by day 7 postoperatively, with no signs of abdominal distension, lethargy or infection (fever, incisional redness/swelling/pus). The mean body weight of the beagles recovered to the pre-modeling level by 4 weeks postoperatively, with a continuous increase thereafter. No delayed hemorrhage, intestinal fistula or other severe complications were observed during the 4-week short-term follow-up.

4.4 6-month long-term follow-up outcomes

All 10 beagles survived the 6-month follow-up period, with significant weight gain compared to pre-operative values. Gastroscopic re-examination at 6 months postoperatively confirmed satisfactory healing of the gastric wall incision in all beagles: the incision was epithelialized, with no redness, erosion, ulcer or incisional hernia; 1–3 soft tissue clamps remained at the incision site in 6 beagles, with no foreign body reaction or leakage (Fig. 3). Exploratory laparotomy at 6 months confirmed no intra-abdominal adhesion recurrence or infectious complications in all beagles: the peritoneal cavity was clear, with no filmy or vascularized adhesions; the intestinal tract was free of dilatation or obstruction, and no intra-abdominal abscess or effusion was found (Fig. 4). All beagles exhibited normal activity, food intake and defecation, with a mean body weight increase of (2.5 ± 0.6) kg compared with the pre-operative level.

5. Discussion

In recent years, the incidence of AIO has been on a steady rise. As a critical factor contributing to short-term and long-term postoperative morbidity and mortality, it exerts adverse effects on patients' health and functional status, with particular prominence in the elderly population [18,19]. A nationwide cohort study demonstrated that the overall incidence of AIO has increased by 50% over the past three decades, becoming a major challenge plaguing healthcare systems worldwide [20,21]. The core clinical dilemma of AIO treatment is the high recurrence rate after conventional surgery, and the development of a more minimally invasive surgical technique to reduce trauma and re-adhesion formation is an urgent clinical need.

Laparoscopic adhesiolysis has become the first-line minimally invasive treatment for AIO, with a 30-day mortality rate significantly lower than that of open surgery [22]. However, laparoscopic surgery still has inherent limitations: (1) it requires multiple abdominal wall puncture incisions, leaving visible scars and

failing to meet patients' aesthetic demands; (2) postoperative shoulder pain is common due to CO₂ pneumoperitoneum, with up to 80% of patients requiring analgesic administration [23,24]; (3) elevated intra-abdominal pressure (12–15 mmHg) may alter the intra-abdominal microenvironment and promote re-adhesion formation. Low-pressure pneumoperitoneum (8–10 mmHg) has been proven to reduce postoperative shoulder pain and adhesion formation [25], and TG-NOTES inherently enables the establishment and maintenance of low-pressure pneumoperitoneum, which is a key advantage over conventional laparoscopic surgery.

NOTES has emerged as a research focus due to its advantages of minimal invasiveness, rapid recovery, cost-effectiveness, and absence of abdominal scars [11]. Different NOTES procedures have their own advantages and limitations: transvaginal NOTES (TV-NOTES) has the advantages of a thin vaginal wall and strong healing ability but is limited to female patients [26]. Transcolorectal NOTES (TC-NOTES) is suitable for pelvic surgery but has a high risk of intra-abdominal infection due to the high bacterial load in the colon [27]. In contrast, TG-NOTES has no gender restrictions and is applicable to all patients. It also boasts a large operative space, extensive surgical field exposure and a well-vascularized gastric wall that facilitates rapid healing after closure. These unique advantages make TG-NOTES a more promising NOTES approach for abdominal surgery, and it has been successfully applied in cholecystectomy, gastric submucosal tumor resection and hepatic cyst unroofing [28–30].

The present study confirmed the safety and feasibility of TG-NOTES adhesiolysis for grade 1–3 AIO in a beagle model, with a 100% technical success rate and no intra-/postoperative complications. TG-NOTES adhesiolysis offers distinct advantages over conventional laparoscopic adhesiolysis: it achieves true scarlessness by avoiding all abdominal wall incisions or punctures, thus fully meeting the aesthetic demands valued by modern patients [11]; it causes no abdominal wall trauma, leading to significant reductions in intraoperative blood loss and postoperative pain while eliminating the risks of incisional hernia and surgical site infection; it mitigates re-adhesion risk by performing the entire procedure under direct gastroscopic vision with low-pressure pneumoperitoneum (8–10 mmHg), which preserves the intestinal tract's normal physiological humidity and temperature and prevents contact between the intestine and foreign bodies such as surgical gloves and talcum powder, thereby reducing intra-abdominal adverse reactions and adhesion reformation; additionally, it has no gender restrictions and broad applicability for all AIO patients, and its large operative space allows application for adhesions in all abdominal quadrants, overcoming the limitations of TV-NOTES and TC-NOTES.

Despite these promising results, several critical technical considerations must be emphasized to ensure the safety of TG-NOTES adhesiolysis. First, thorough gastric cavity disinfection is essential, as transgastric access poses a cross-infection risk between the gastric cavity and peritoneal cavity; irrigating and disinfecting the gastric cavity with chlorhexidine or povidone-iodine solution effectively reduces this risk [31]. Second, accurate abdominal localization requires external abdominal compression combined with transillumination to identify the optimal gastric wall incision and adhesion sites, given the insufficient rigidity of gastroscopic instruments, and the use of a snare or guidewire can further enhance intraoperative localization accuracy [32,33]. Third, reliable gastric wall closure is pivotal for

preventing postoperative leakage and fistula formation, with soft tissue clamps serving as a simple and effective method—optimizing the number and spacing of clamps (2–3 clamps for a 1.0-1.5 cm incision) ensures tight closure. Finally, TG-NOTES adhesiolysis demands operators with solid expertise in both digestive endoscopy and abdominal surgery, including proficient mastery of abdominal anatomy, endoscopic dissection techniques, and intraoperative complication management, meaning such procedures should only be performed by experienced interdisciplinary surgeons with dual training in gastroenterology and general surgery. In addition, indications for TG-NOTES adhesiolysis should be strictly controlled in clinical translation and application. The initial clinical application should be limited to local mild adhesions, and multi-organ involvement and dense adhesions should be excluded. Adequate preparation and emergency plans should be made.

This study has several limitations that warrant attention in future research. First, as an exploratory study of a novel technique, this research only verified its feasibility and preliminary safety without setting up a control group. The lack of comparative data prevented statistical analysis of key outcome indicators, thus limiting the objective evaluation of the technique's advantages, disadvantages, and clinical value. Second, the follow-up period for postoperative adhesion recurrence was limited to 6 months. Given the chronic and progressive nature of intra-abdominal adhesions, short-term follow-up may miss late recurrence. And there may be microscopic adhesions or inflammatory changes that are not visible to the naked eye. It is necessary to extend the follow-up duration to accurately evaluate the stability of long-term efficacy. Incorporating functional and biological indicators (e.g., intestinal flora homeostasis) would further improve the completeness of the physiological evaluation system, enabling a comprehensive and multi-dimensional assessment of therapeutic efficacy. Third, the established model only simulates grade 1–3 adhesions and does not cover grade 4 severe adhesions. Clinically, adhesions are characterized by complex etiologies and chronic pathophysiological mechanisms. Future studies should develop clinically relevant models with severe, chronic, and complex-site adhesions to verify the applicability of this technique in complicated cases. Fourth, the small sample size restricted the external validity of the preliminary findings on safety and feasibility. Subsequent confirmatory studies should expand the sample size and adopt a multicenter collaborative design to reduce bias. During clinical translation, establishing standardized operating procedures, diagnostic protocols, therapeutic protocols, and adverse event early warning mechanisms is essential to verify universal applicability.

6. Conclusion

Preliminary experimental results in a beagle model confirm that TG-NOTES adhesiolysis is a safe, effective and scarless minimally invasive procedure for the treatment of grade 1–3 adhesive intestinal obstruction. This technique has the advantages of minimal intraoperative blood loss, stable vital signs, no short-term/long-term complications and no adhesion recurrence within 6 months, and it fully meets the growing aesthetic demands of patients. Although further research (large sample, control group, long-term follow-up) is needed to verify its long-term efficacy and clinical applicability, TG-NOTES adhesiolysis holds promising potential as an innovative therapeutic option for adhesive intestinal obstruction and provides a solid experimental basis for subsequent clinical translation.

Declarations

Ethics approval

Our study was permitted by the Ethics Committee of the 900th Hospital of PLA Joint Logistic Support Force. The ethics approval ID is No.2023-53. All experimental procedures were complied with the Guide for the Care and Use of Laboratory Animals (8th edition, NIH).

Consent for publication

The authors agreed.

Competing interests

All authors declared that they had no conflict of interest.

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Author Contribution

Wen Lin, Chuan-Shen Jiang, Xin-Yi Zheng participated in the design of study and manuscript writing. Dong-Gui Hong, Long-Ping Chen, Yan Zhuang, Han Lin participated in the acquisition of data and analysis. Wen Wang, Xiao-Jian He and Da-Zhou Li contributed to the project administration and supervision.

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Not applicable.

Data Availability

The data supporting this article will be made available upon reasonable request to the corresponding author.

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Figures

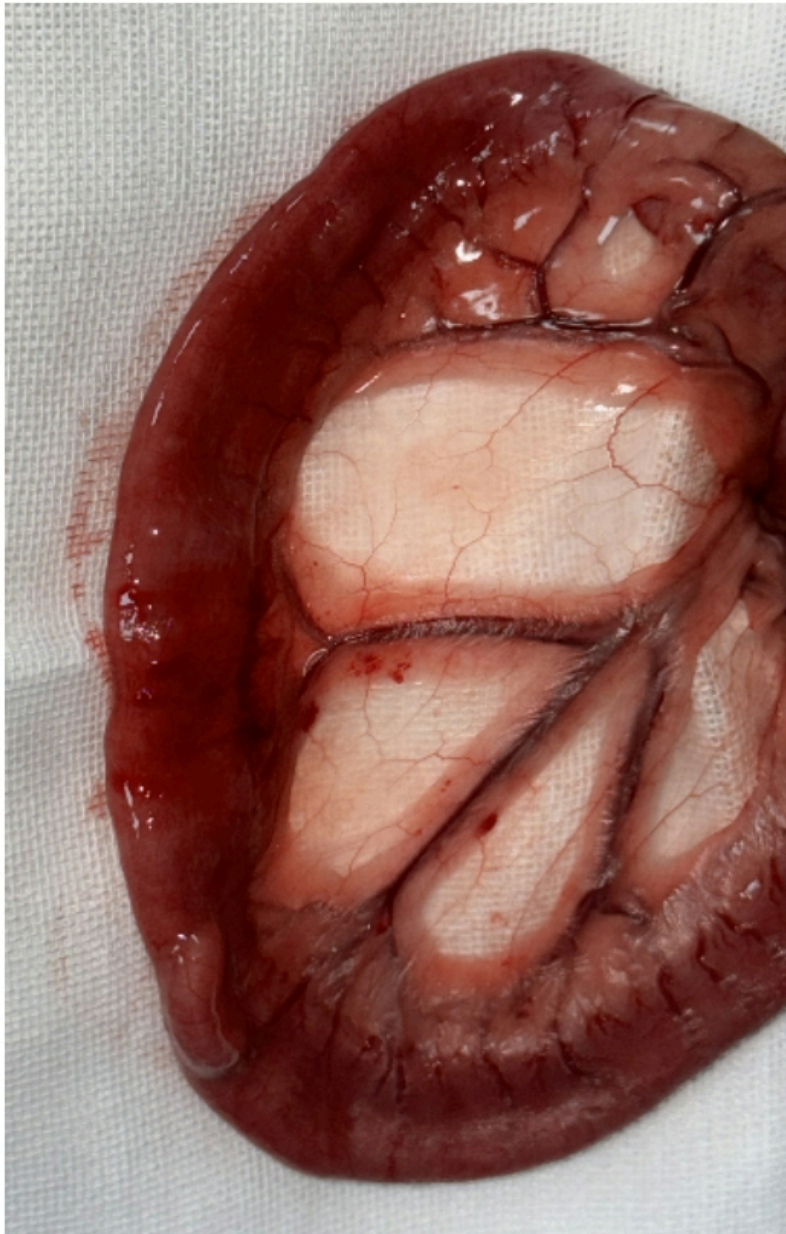


Figure 1

Construction of adhesive intestinal obstruction model using serosal injury and chemical stimulation

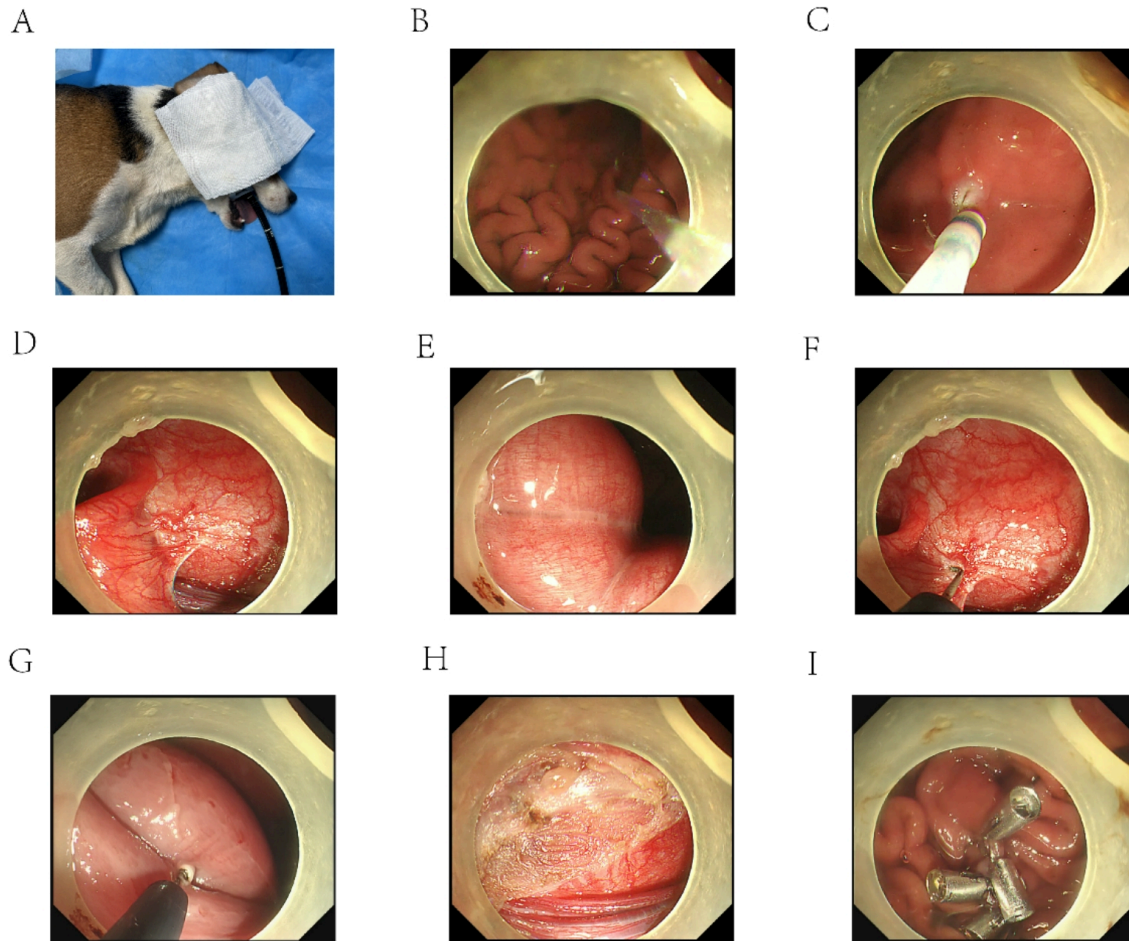


Figure 2

The complete process of TG-NOTES abdominal exploration and adhesiolysis. (A) the beagle was placed on the operating table in the left lateral decubitus position. (B) Rinse the stomach cavity with sterile water. (C) The stomach wall was cut by dual knife. (D) The adhesion band under direct vision of the gastroscopy. (E) Edematous and dilated intestine. (F) The adhesion band was separated by a hook knife. (G) The adhesion band was separated by a nano knife. (H) The adhesion band was completely separated. (I) The gastrotomy incision was closed with soft tissue clamps.

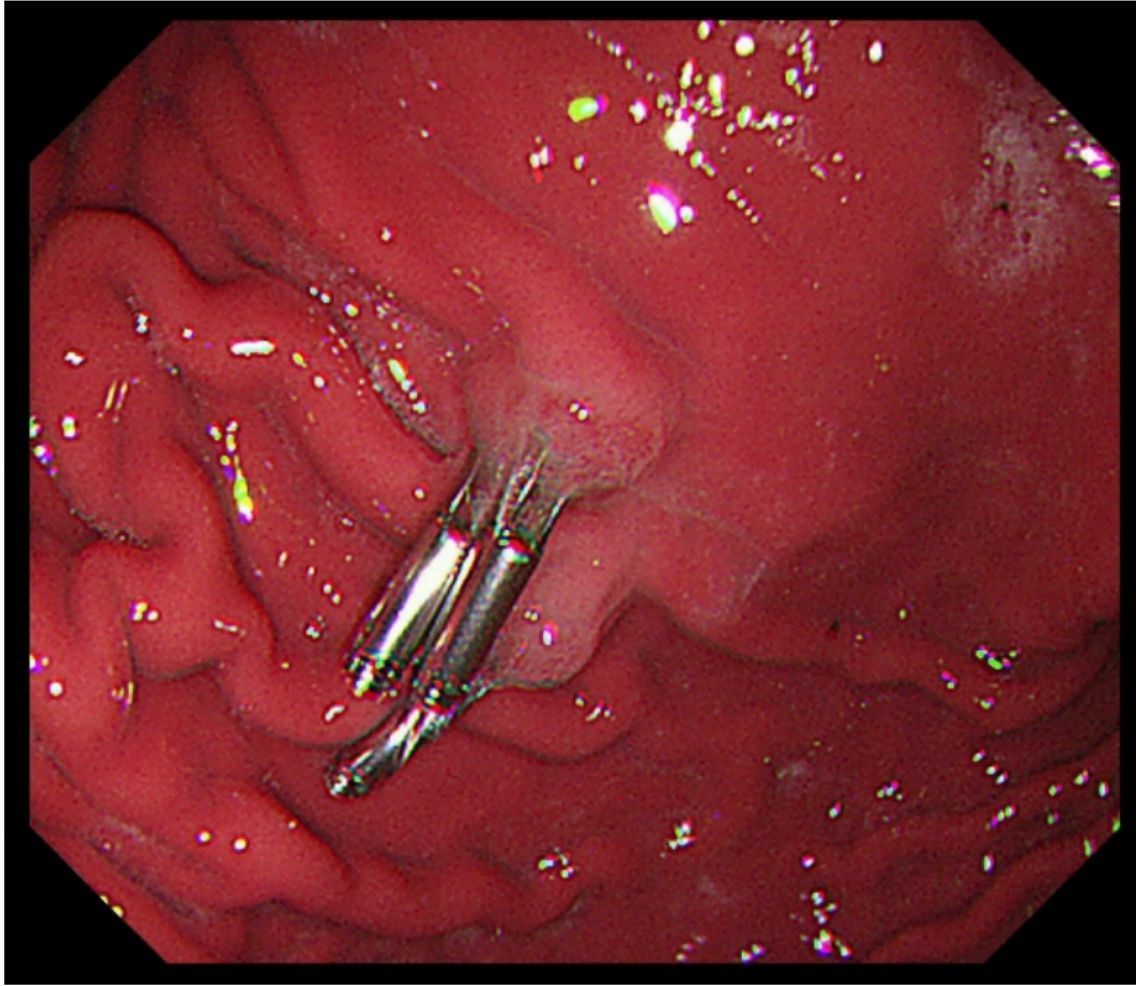


Figure 3

The gastric wall incision healed well, and some soft tissue clips remained.



Figure 4

Recurrent adhesions or intra-abdominal infection were not detected.