NOTES for the management of an intra-abdominal abscess: transcolonic peritonoscopy and abscess drainage in a canine model

Fady Moustarah, MD, MPH*†
Joseph Talarico, MD*
Jill Zinc, MD*
Patrick Gatmaitan, MD*
Stacy Brethauer, MD*

From the *Bariatric and Metabolic Institute, Cleveland Clinic Foundation, Ohio, and the †Département de chirurgie, Université Laval, Québec, Que.

Accepted for publication
Mar. 22, 2012

Correspondence to:
F. Moustarah
Professeur associé, département de chirurgie, Université Laval
Chirurgie Générale, l'IUCPQ
2725, Chemin Sainte-Foy
Québec QC G1V 4G5
f.moustarah@hotmail.com

DOI: 10.1503/cjs.037111

Background: We studied natural orifice transcolonic drainage of intra-abdominal abscesses in a canine survival model to evaluate the difficulty of peritonoscopy and abscess drainage and the reliability of endoluminal colotomy closure.

Methods: We placed a 7 cm nonsterile saline-filled latex balloon intra-abdominally to mimic or induce an abscess or inflammatory mass. Seven days later, we advanced a single-channel endoscope transanally into the sigmoid colon of the animal, made a colotomy and then advanced the endoscope intraperitoneally. We evacuated the identified abscess and placed a drain transabdominally. We closed the colotomy endoluminally with a tissue approximation system using 2 polypropylene sutures attached to metal T-bars. Two weeks later, we evaluated the colotomy closure at laparotomy.

Results: We studied 12 dogs: 8 had subphrenic balloon implants and 4 had interbowel loop implants. Eleven survived and underwent transcolonic peritonoscopy; we identified the "abscess" in 9. The colotomy was successfully closed in 10 of 11 dogs. Although abscesses were easily identified, the overall difficulty of the peritonoscopy was moderate to severe. One dog required colotomy closure via laparotomy, while 9 had successful endoluminal closure. After colotomy closure, 8 animals survived for 2 weeks (study end point) without surgical complications, sepsis or localized abdominal infections. On postmortem examination, all closures were intact without any adjacent organ damage or procedure-related complications.

Conclusion: Natural orifice transluminal endoscopic surgery provides a novel alternative to treating intra-abdominal pathology. It is technically feasible to perform endoscopic transcolonic peritonoscopy and drainage of an intra-abdominal abscess with reliable closure of the colotomy in a canine experimental model.

Contexte : Nous avons étudié le drainage transcolique par voie naturelle d'abcès intra-abdominaux dans un modèle canin de survie afin d'évaluer la difficulté de la péritonoscopie et du drainage des abcès, ainsi que la fiabilité de la fermeture endoluminale de la colotomie.

Méthodes : Nous avons inséré un ballonnet de latex de 7 cm non stérile empli de solution physiologique par voie intra-abdominale pour simuler ou induire un abcès ou une masse inflammatoire. Sept jours plus tard, nous avons introduit un endoscope à simple canal par voie transanale jusqu'au sigmoïde de l'animal, procédé à une colotomie et ensuite poussé l'endoscope dans le péritoine. Nous avons vidé l'abcès observé et placé un drain par voie transabdominale. Nous avons ensuite procédé à une fermeture endoluminale de la colotomie avec un système de rapprochement tissulaire utilisant 2 sutures de polypropylène fixées à des pièces métalliques en T. Deux semaines plus tard, nous avons évalué la fermeture de la colotomie par laparotomie.

Résultats : Notre étude a porté sur 12 chiens : 8 avaient un ballonnet implanté au niveau sous-phrénique et 4, entre les anses intestinales. Onze ont survécu et ont subi la péritonoscopie transcolique; nous avons retracé « l'abcès » chez 9 d'entre eux. La colotomie a été refermée avec succès chez 10 chiens sur 11. Même s'il a été facile de retracer les abcès, la difficulté globale de la péritonoscopie a été jugée de modérée à marquée. Un chien a eu besoin d'une fermeture de colotomie par laparotomie, tandis que la fermeture endoluminale a réussi chez 9 animaux. Après la fermeture de la colotomie, 8 chiens ont survécu 2 semaines (fin de l'étude) sans complications chirurgicales, sepsis ni infections abdominales localisées. À l'autopsie, toutes les fermetures étaient intactes, sans atteinte aux organes adjacents ni complications des suites de l'intervention.

Conclusion : La chirurgie endoscopique transluminale par voie naturelle offre une solution de rechange pour le traitement des pathologies intra-abdominales. Il est possible au plan technique de réaliser une péritonoscopie transcolique endoscopique et de drainer un abcès intra-abdominal avec fermeture fiable de la colotomie dans un modèle expérimental chez le chien.

Intra-abdominal abscesses are commonly encountered in clinical practice. Although multiple methods exist for their drainage, adding natural orifice transluminal endoscopic surgery (NOTES) to the armamentarium of the clinician may allow for drainage of some difficult-to-reach abscesses that are not deemed optimal for radiologically guided percutaneous drainage and that would otherwise necessitate treatment with open or laparoscopic surgery. Management of an intra-abdominal abscess by transcolonic endoscopy involves a number of important considerations: safe creation of a colotomy, performance of an adequate peritonoscopy, accurate identification and drainage of an abscess, removal of necrotic tissue if present, and performance of a reliable colotomy closure, all while minimizing risks of any resultant surgical site infection and diffuse sepsis. To evaluate the safety and feasibility of employing NOTES for abdominal abscess management and colotomy closure, we developed a short survival animal model. We hypothesized that transcolonic peritonoscopy and drainage of an intra-abdominal abscess could be safely performed in a canine model with adequate closure and healing of the colotomy access site.

Methods

This study was approved by the Institutional Animal Care and Utilization Committee (IACUC) at the Cleveland Clinic Foundation (CCF) and was conducted in accordance with the U.S. Department of Agriculture Animal Welfare Act, Public Health Service policy, the Health Research Extension Act (PL99–158) and CCF policy. All animals were housed and cared for at the Cleveland Clinic Biological Resources Unit.

We used 12 dogs (average weight 26 kg) for this 3-phase survival study. Phase 1 involved inducing an intra-abdominal abscess in 1 of 2 locations: the left subphrenic space or the lower abdomen between bowel loops. Phase 2 began after 7 days and involved performing the transcolonic diagnostic peritonoscopy, drainage of the abscess and closure of the colotomy. Two weeks later, the surviving animals entered phase 3 of the study, in which they were euthanized and in which we evaluated the reliability of colonic closure for presence or absence of complete healing. We also looked for abscesses, fistulas, gross macroscopic acute inflammation and surrounding organ injury. The experimental methods are described in more detail in the sections that follow.

Animal preparation and anesthesia

Animals were fed a liquid diet for 2 days before the initial laparotomy, which was performed to induce abscess formation. The dogs were also kept fasting for 12 hours before a planned procedure. We applied a 75 µg/h fentanyl patch the night before surgery for perioperative pain control. The morning of the procedure, a peripheral intravenous line was placed. Antibiotic prophylaxis was not used since the goal was to induce intra-abdominal abscess formation. All procedures (surgical and/or endoscopic) were performed under general anesthesia. We used a loading dose of intravenous thiopental (20mg/kg) for induction, and the dose was titrated to effect. After intubation, we maintained anesthesia using inhalation isoflurane (1%–2.5%). We used a 75 mcg/h fentanyl patch (100 mcg/h for dogs > 30 kg) for postoperative analgesia.

Phase 1: intra-abdominal balloon placement

In the supine position and under general anesthesia, a 10-top 15-cm midline laparotomy incision was made using a standard operating aseptic technique. We entered and explored the abdomen to identify any pre-existing pathology. We then implanted a nonsterile latex, saline-filled balloon measuring 7 cm in diameter to induce an inflammatory response (abscess) around the balloon in the left subphrenic space or between small bowel loops at the level of the aortic bifurcation in the lower abdomen. The balloon was secured in place with suture to surrounding tissue to prevent migration. The abdominal viscera were returned to the normal position, and the fascia was closed with 0-prolene suture. The skin was closed in 2 layers using 3–0 vicryl suture. We monitored the animals postoperatively for 7 days to allow an inflammatory reaction and abscess to develop around the balloon. Postoperative therapy and analgesia were administered according to protocol and as deemed necessary by our supervising veterinarian. The animals had free access to water the night of the procedure and resumed a regular diet the following day. We monitored oral intake, hydration status, temperature and heart rate.

Phase 2: transcolonic NOTES

On the sixth postoperative day, dogs were started on a clear liquid diet and received a 45 mL phosphasoda mechanical bowel preparation. The transcolonic NOTES procedure was performed the following morning (1 week after balloon implantation) under general anesthesia and after administration of a betadine enema immediately before endoscopy. We administered 30 mg/kg of cefoxitin

intravenously 30 minutes before surgery. A single-channel therapeutic endoscope was then introduced through the anus and advanced to the proximal rectum/sigmoid colon, where a colotomy was created 15–20 cm from the anus. We marked the site of the colotomy with a resolution clip placed in the vicinity for easy identification on advancement or withdrawal of the endoscope during the procedure. We used a needle knife to create the colotomy, which was in turn enlarged with an 18 mm controlled radial expansion dilating balloon catheter. The scope was then advanced into the peritoneal cavity, and we used CO_2 to insufflate the abdomen to 8–10 mm Hg and create the working space. The abdomen was systematically explored. Changes in the operating table position and endoscopic bowel manipulation with a flexible atraumatic endoscopic grasper assisted in evaluating peritoneal reflections in the pelvis, sigmoid colon, appendix, midjejunum, right lobe of liver, right subphrenic space, lesser curvature of the stomach and left subphrenic space. For each area examined, the endoscopist graded the level of difficulty required to achieve an adequate view of the target area (0 = no difficulty, 1 = minimal difficulty, 2 = moderate difficulty, 3 = severe difficulty, 4 = unable to achieve an adequate view).

Attention was then turned to the known area of the abscess (location of the previously placed balloon). The abscess was exposed, punctured and drained using a needle through the endoscope. We then passed a closed-suction drain through a small stab incision in the abdominal wall and placed it within the abscess cavity using an endoscopic grasper. The drain was secured in place at the skin and placed to bulb suction postoperatively. We removed the deflated balloon from the abdominal cavity through the colotomy using the endoscope and then closed the colotomy using the tissue approximation system (TAS; Ethicon Endo-surgery, Inc.), which has been described previously.[1] The TAS consisted of a 3–0 polypropylene thread attached to a metal T-tag, which was loaded in a plastic-covered, long, hollow needle (inner diameter 0.028 inches + 0.0005 inches/–0.001 inches) with a stylet to dislodge the T-tag. The loaded system was introduced through a working channel of the endoscope, and the loaded needle was advanced through the edge of the colotomy under endoscopic vision. By advancing the stylet, the T portion of the tag was deployed on the serosal side of the colon and the system removed. The system was reloaded and the same was performed at the opposite wound edge. We then tightened both sutures and secured with a knotting element (implantable polymer). The closure was tested at the end of the procedure by its ability to hold gas in the colonic lumen, thereby maintaining colonic distention under insufflation pressure.

Postoperative management included the administration of Baytril (5mg/kg) orally once daily for 7 days after surgery. We monitored oral intake, hydration status, temperature and heart rate, and we placed a 75 µg/kg fentanyl patch (100 µg/kg for dogs > 30 kg) for postoperative pain control. We administered buprenorphine (0.02 mg/kg) subcutaneously every 12 hours as needed for breakthrough pain. The animals were kept on a liquid diet (Boost) for 1 week postoperatively and then advanced to a soft regular diet (canned food). We removed the drain when drainage became serous or when it decreased below 20 mL in a 24-hour period.

Phase 3: euthanasia and evaluation of abdomen and colotomy closure

Two weeks after the NOTES procedure, we opened the previous laparotomy incision under general anesthesia. We explored the abdomen for signs of inflammation or infection in the form of peritonitis, abscesses, fistulas, leaks and/or adhesions. We inspected the integrity of the colotomy and gastrotomy and evaluated the site of the abscess and drain (if still present). Finally, we administered pentobarbitol (100 mg/kg) intravenously to euthanize the animals according to protocol. We resected the segment of colon containing the former colotomy site for examination.

Results

Our initial sample consisted of 12 dogs, which we studied between October 2008 and May 2009. Their average weight was 25.5 (standard deviation of 3.3, range 19.2–29.6) kg. Eight animals had balloons implanted in the left subphrenic position, and 4 had an interloop lower abdominal balloon implant. The flow of animals through different stages of our experimental protocol is depicted in Figure 1. One dog had a fascial dehiscence during phase 1 and therefore exited the study before reaching phase 2. Eleven dogs reached phase 2 and underwent a transcolonic peritonoscopy. Transcolonic peritoneal access was achieved without any immediate complications in the remaining 11 dogs. At the time of diagnostic peritonoscopy and abscess drainage (phase 2), 1 dog exited the study owing to a bladder injury, leaving 10 dogs

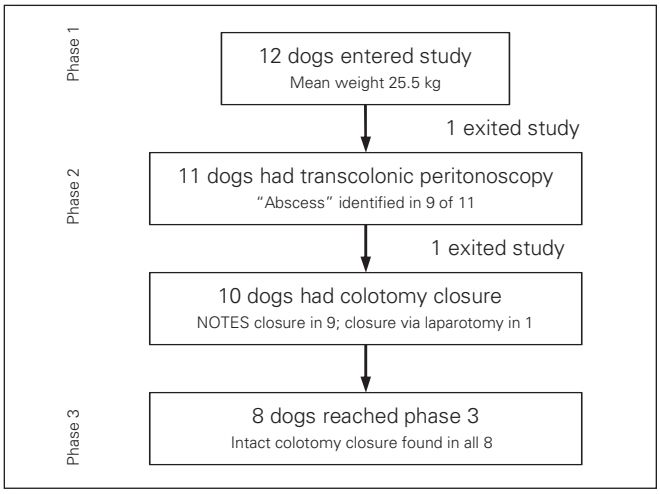

Fig. 1. Study sample size and flow of dogs through experimental protocol.

for colotomy closure. Of these 10, the first dog in the series needed its colotomy closed by open laparotomy, and the other 9 had endoscopic closure of their colotomies using the TAS system. The overall difficulty of the peritonoscopy was rated as moderate to severe owing to difficulties encountered in viewing lower abdominal organs. Pelvic peritoneal reflections and structures were more difficult to identify and evaluate with an endoscope, as rated by the operator, than the subphrenic spaces. Most identified abscesses, however, were seen with minimal difficulty. A frequency distribution of the relative ease of abscess identification is depicted in Figure 2. The subphrenic versus interbowel loop location of the abscess did not appear to influence the ease of identification (Table 1). After colotomy closure, 8 animals survived for 2 weeks (study end point) without surgical complications, sepsis or localized abdominal infections. Two animals exited the study during phase 2: 1 owing to abdominal wound dehiscence and 1 owing to hemorrhage in the early postoperative period. Of the 8 animals that reached phase 3, postmortem examinations revealed all closures to be intact without adjacent organ damage, infection, substantial gross inflammation or procedure-related complications. We occasionally noted minor filmy adhesions between the colotomy site and adjacent structures (fat or anterior abdominal wall). In vivo and ex vivo images of a colotomy closed with TAS taken at the end of the study are shown in Figure 3. In 1 dog, the T-tag was anchored to the anterior abdominal wall without any associated injury.

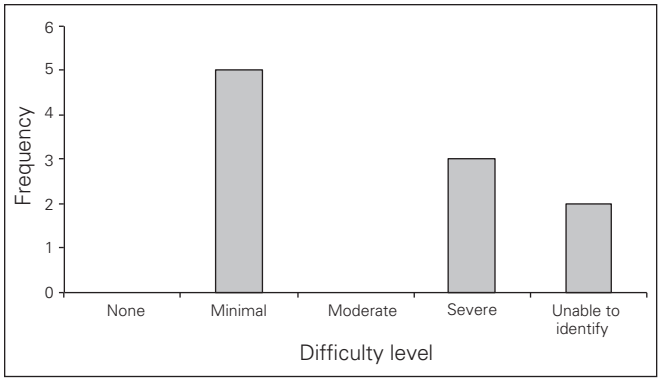

Fig. 2. Relative difficulty experienced by an operator using transcolonic peritonoscopy to identify an intra-abdominal "abcess."

Table 1. The relative difficulty experienced by an operator using transcolonic peritonoscopy to identify an intra-abdominal abcess depending on its location*

Location	Easy	Difficult	Total
Subphrenic	4	2	6
Interloop	1	3	4
Total	5	5	10

*Fisher exact test, $p = 0.52$, indicating no significant association between subphrenic or interloop abscess location and ease or difficulty of abscess identification during transcolonic peritonoscopy.

Discussion

Natural orifice transluminal endoscopic surgery is a new and exciting milestone in surgical endoscopy, where flexible endoscopic equipment is passed through natural orifices to perform visceral incisions and allow access to the abdominal cavity. Since Kalloo and colleagues[2] and Rao and Reddy[3] demonstrated the feasibility of accessing the peritoneal cavity for diagnostic and therapeutic work around the turn of the century, there has been marked enthusiasm for expanding the applicability of NOTES and for research in the area.[4] To promote responsible growth in this emerging field, a white paper on NOTES was produced in October 2005 by a working group from the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the American Society for Gastrointestinal Endoscopy (ASGE), later known as the Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR). The white paper outlined the fundamental challenges facing NOTES and the principal areas of research required for its safe introduction into the clinical arena.[5,6] Choice of access to the peritoneal cavity, reliability of visceral closure, prevention of infection, and development of stable technology and platforms were some of the important areas identified for further research and development.

Whereas initial feasibility experiments used the transgastric approach to the peritoneum,[2] there has been recent interest in other routes of access. In experimental settings, the peritoneal cavity has also been accessed through the vagina,[7,8] bladder[9] and colon.[10–12] Working within the NOSCAR framework for research, to our knowledge, our group is the first to study the feasibility of diagnosing and draining an intra-abdominal abscess through the transcolonic route in a canine survival model, where access, closure and healing of the colotomy were also under investigation. There are few reports on the transcolonic

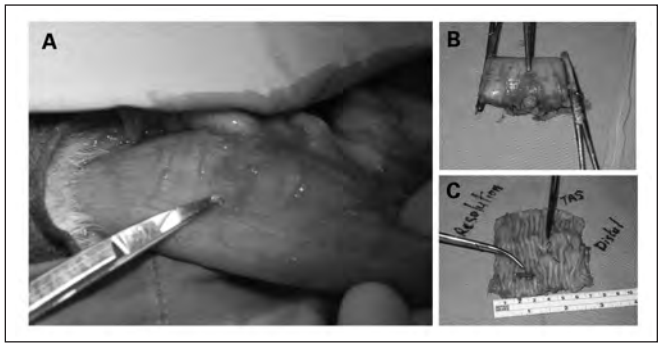

Fig. 3. In vivo and ex vivo images of colotomy closure site at the end of the study. Pointing instruments identify site of healing after NOTES closure on the external and internal colonic surfaces. Intraluminally, a Resolution (metallic clip) is identified, and the anchor and blue suture from the tissue approximating system is also noted in the ex vivo resected specimen 2 weeks after insertion.

approach, and the technique has mostly been used in porcine experiments. Although fraught with concerns relating to peritoneal infection and sepsis, the transcolonic approach does offer a unique set of advantages over the transgastric route.

Our literature review revealed no standardized and reproducible model of intra-abdominal abscess in dogs. We developed a model whereby a nonsterile, saline-filled latex balloon is placed in the peritoneal cavity, and a period of 7 days is allowed for the development of an inflammatory or infectious mass. At the time of the NOTES procedure, we observed that an inflammatory reaction to the latex developed, walling off of the balloon and creating the mass effect ("abscess") needed for the purpose of our study. Fortunately, the animals did not experience florid sepsis between the time of balloon implantation and the time of NOTES peritonoscopy. It remains uncertain whether prolonging phase 1 of our study would have resulted in more of an infectious intra-abdominal process versus the inflammatory one that we observed or whether that would have affected efforts at the time of diagnostic NOTES and abscess drainage due to local or diffuse sepsis or intraperitoneal adhesions.

Access to the peritoneal cavity has been experimentally achieved using flexible endoscopes through various natural orifices, including the mouth, anus, urethra and vagina. To this date, the best route and method of access has not been reliably established. We believe the best NOTES access will ultimately be procedure-dependent, especially as advances in instrumentation are made and as our understanding and control of the route-specific biology and pathophysiology improves. Early access techniques were developed for creating gastrotomies and were later applied to the colon.[2,4,10] The technique used in our study is similar to that used by others: we used readily available endoscopic accessories, such as a single-channel endoscope, a needle knife, endoclips and dilation balloons, to create the colotomy. Placing an endoclip in the vicinity of the planned colotomy was deemed helpful in localizing the incision site as the endoscope was moved back and forth in the colon. This clipping technique was preferable to inking the mucosa in the vicinity so as not to impair visibility from ink staining in the area during handling. The colonic incision was created 15–20 cm from the anus, and we found this to give reliable access to the peritoneal cavity without injury to adjacent viscera. The incision was made higher in the colon in the first animal, and this necessitated closure of the colotomy site through an open laparotomy owing to difficulties encountered with endoscopic T-tag closure more than 20 cm from the anal orifice. All other animals remaining in the study had NOTES closure of their colotomy. Our experience with the colotomy at 15–20 cm is consistent with that of other investigators who found this location suitable for their transcolonic peritoneal work.[1,13,14]

A fundamental barrier to moving NOTES from the experimental to the clinical arena has been the ability to achieve reliable and uncomplicated closure of the endoscopically created visceral incisions.[5] In fact, members of SAGES and ASGE recommended that access site closure reach 100% reliability before NOTES is approved for clinical trials in the United States.[5,15]

Balloon-dilated gastrotomies in a porcine model have been observed to close spontaneously without specific efforts directed at closure.[16] However, incomplete access site closure in pigs has also been reported and resulted in complications as severe as frank peritonitis.[17] Questions then arose as to whether the porcine model is most suited for peritoneal access studies, especially considering the microbiologic, immunologic and anatomic issues in pigs compared with human conditions.[2,10,17,18]

We investigated colotomy closure in a canine model, and although bacteriologic examination of the peritoneum was not performed, there was no evidence of gross peritonitis or severe local pericolonic inflammation in any of the 8 dogs that reached the study end point. The colotomy incisions were closed with TAS (metallic T-tags on nonabsorbable sutures), and occasionally a Resolution endoclip was applied to improve on mucosal approximation when deemed necessary by the operator. Other investigators have previously described using T-tag anchors for visceral closure.[1,13,14,19,20] Concerns regarding iatrogenic injury to abdominal organs has arisen. Sumiyama and colleagues[19] reported 3 of 24 tags used penetrate surrounding organs, and Mathews and colleagues[13] reported injury to surrounding structures in 75% of their cases. Sporn and colleagues[1] used the TAS system for colotomy closure with no reported injuries, but this was done with laparoscopic assistance. Others have demonstrated that without laparoscopic control, TAS colotomy closures can be safely performed.[21]

Developers of the TAS system recommend laparoscopic visualization during deployment of the T-tags. We used a pure NOTES approach in our experiment without the use of a laparoscope, and we were able to place T-tags accurately and in a controlled fashion. We experienced occasional technical failures, such as suture wrapping after introducing the second T-tag suture through the channel of the endoscope and breakage of the device before deployment requiring extra time for reloading. At necropsy, we found that T-tags anchored to the anterior abdominal wall in some animals. In 1 animal, bleeding in the postoperative period after an uneventful colotomy closure during NOTES was secondary to a splenic capsule puncture occurring during T-tag placement and resulting in an initially unrecognized bleeding event presenting as delayed postoperative hemorrhage. Without laparoscopic control, penetration of surrounding structures during T-tag placement seems unpredictable. Further work is needed in this area to study various closure methods (full v. partial thickness) and different closure devices, and many are currently under active investigation.

The ability to maintain an insufflated colon and a good luminal endoscopic view indicated adequate closure of the colotomy in our experiment. Specific leak tests are not yet available for this setting. The Hopkins' group has already started experimenting with an $H_{2(g)}$-based leak test in a porcine model with good results.[22] Leak tests may find a place in this area of NOTES to improve the reliability of tissue closure, and perhaps more importantly to enhance the reassurance of obtaining a complete fluid tight closure at the time of the procedure.

Peritonoscopy through a natural orifice has been shown to be feasible in several studies in both animal models and in human case series.[2,11,23–26] Our study introduces an "abscess" into the abdominal cavity to assess transcolonic peritonoscopy in this setting. Specifically, we wanted to examine our ability to adequately visualize important predetermined areas: the peritoneal reflection in the pelvis, sigmoid colon, appendix, midjejunum, right lobe of the liver, right subphrenic space, lesser curvature of the stomach and left hepatic space. For each area examined, the endoscopist graded the level of difficulty required to achieve an adequate view of the target area on a 5-point scale. Consistent with other reports,[11,14] we found it more challenging to identify pelvic and lower abdominal structures than upper abdominal organs. The appendix was most challenging to visualize. One of the dogs sustained a bladder injury because visualization in the lower abdomen was less than optimal, and the distended bladder was mistaken for the abscess. Catheterizing the bladder for such future experiments may be useful. The transcolonic approach to peritonoscopy has been used by only a few investigators. Pai and colleagues[10] used the transcolonic approach to perform a cholecystectomy in a survival porcine model owing to easier visualization of the upper quadrants and conduction of the procedure. This was later followed by a report from Fong and colleagues,[11] who studied transcolonic peritonoscopy more specifically and described it as a novel approach to explore the abdominal cavity. They found that, in contrast to the transgastric method, the transcolonic approach provides more consistent identification of structures in the upper abdomen and provides better orientation and scope stability; their visualization of lower abdominal areas was, however, more limited, as we experienced. In contrast to these findings, Sporn and colleagues[1] were able to adequately visualize all 4 quadrants of the abdomen while exploring it transcolonically. They explained that maintaining the pneumoperitoneum with a laparoscopic port and using pronounced Trendelenberg positions may have contributed to the completeness of their transcolonic peritonoscopy. Kim and colleagues[27] and Voermans and colleagues[14] designed experiments where transcolonic and transgastric peritonoscopy were compared directly in the same study. They both agreed on the superiority of the transcolonic method in allowing for a more complete diagnostic peritonoscopy and overcoming the limitations of the transgastric method when it comes to visualizing upper abdominal structures. Identification of the abscess in our study was relatively easy, and the diagnostic yield of the transcolonic NOTES peritonoscopy was not influenced by whether the abscess was in the upper or lower parts of the canine abdomen.

Abdominal abscesses result from many common clinical conditions, such as diverticulitis, appendicitis, pelvic inflammatory disease and anastomotic leaks after gastrointestinal surgery. The mainstay of therapy is abscess drainage with adjunctive antibiotics.[28] In most cases involving an abscess of moderate size, drainage is achieved percutaneously under radiographic guidance.[29–31] However, a safe window for percutaneous drainage is not always present, and patients often undergo open or laparoscopic surgical drainage of the intra-abdominal collection. Natural orifice transluminal endoscopic surgery is currently an experimental alternative to such approaches, which would avoid abdominal incisions and potentially reduce pain and postoperative stay in hospital. To our knowledge, our study is the first animal NOTES experiment assessing abdominal abscess drainage. After diagnosis, abscesses were easily drained by either needle puncture or by unroofing the inflammatory wall over the implanted latex balloon with monopolar current applied to a hot biopsy forceps. We were able to drain the abscesses completely. This may have been possible because the balloons were filled with saline, which drained easily; it could have been more difficult had pus and debris collected in the centre of the inflammatory mass induced by the implanted nonsterile balloon. Also, we were often able to remove only part of the balloon, as it was well incorporated into the wall of inflammation in some instances. It remains uncertain how successful drainage and treatment of an abscess in our model would have been had it been multiloculated or filled with thick debris and exudate. After draining the abscess cavity with endoscopic instruments, we proceed to place a percutaneous Jackson–Pratt drain in the centre of the abscess cavity under endosopic vision. Of note is that in many instances, the dogs would not keep the drains in place for very long postoperatively.

Limitations

Transcolonic peritonoscopy and abscess drainage was successfully undertaken with good healing of the colotomies with the T-tag closure methods used in our study. Limitations of the model include the development of a reactive inflammatory mass to the contaminated balloon implant, which was not representative of a true abscess process, and the small sample. Inoculating the nonsterile balloons with enteric flora and prolonging phase 1 of the study may have led to a better abscess model, but this may also have put the animals at risk for sepsis. The endoscopist was not blinded to the location of the abscess, which may have

biased the ease of the peritonoscopy, although this effect is limited to identification of the abscess. A requirement of the diagnostic study was that a number of predetermined areas be visually examined during the exploration in all animals. We also experienced technical limitations imposed by the basic endoscopic instruments used. A double-channel endoscope, more advanced flexible instruments and better-designed closure technology could enhance the diagnostic and therapeutic capabilities of transcolonic NOTES peritonoscopy and abscess drainage. There are clear advantages to the transcolonic approach pertaining to ease of access and improved visualization of the upper abdomen.

Conclusion

Natural orifice transluminal endoscopic surgery is a modern surgical breakthrough promising no visible scars, and it is moving slowly from the experimental to the clinical arena. This slow progression is both deliberate and useful to ensure its safety and therapeutic efficacy before its widespread dissemination. At present, attitudes regarding NOTES remain discordant between patients and surgeons. Patients seem to be early adopters of the technology, perhaps owing to a perception that surgical risk is related to incision size, whereas surgeons prefer to wait for more safety and efficacy outcome data.[32] Years after NOSCAR published the white paper on NOTES in 2005, and although various NOTES procedures have now been tested in humans,[25,26,33–36] investigators continue to rely on animal models to better understand and overcome several of the barriers precluding NOTES from wide clinical adoption. In brief, we have shown the feasibility of transcolonic NOTES peritonoscopy and abscess drainage in a canine survival study. Colotomy closure has been reliable, but the risk of complications from T-tag insertion remains. Therapeutic interventions in the upper abdomen, including organ resection, may be more achievable using transcolonic methods; however, further studies are needed to resolve issues of surgical site infection and safe colonic closure. Industry interest and support continues to be vital to progress in this field, and it remains a promising time for doctors, engineers and businesses to collaborate and deliver innovative minimal access solutions to common surgical problems.

Competing interests: None declared by F. Moustarah, J. Talarico, J. Zinc and P. Gatmaitan. S. Brethauer is a consultant, scientific advisory board member and speaker for Ethicon Endo-Surgery and receives grant support from them; he is also a speaker for Covidien and a consultant for Apollo Endosurgery. This study was funded by a NOSCAR grant and a grant from Ethicon Endo-Surgery was received to use the TAS system.

Contributors: F. Moustarah, J. Talarico, P. Gatmaitan and S. Brethauer designed the study. F. Moustarah, J. Talarico and S. Brethauer analyzed the data. F. Moustarah wrote the article. All authors acquired data, reviewed the article and approved its publication.

References

1. Sporn E, Bachman SL, Miedema BW, et al. Endoscopic colotomy closure for natural orifice transluminal endoscopic surgery using a T-fastener prototype in comparison to conventional laparoscopic suture closure. *Gastrointest Endosc* 2008;68:724-30.
2. Kalloo AN, Singh VK, Jagannath SB, et al. Flexible transgastric peritoneoscopy: a novel approach to diagnostic and therapeutic interventions in the peritoneal cavity. *Gastrointest Endosc* 2004;60:114-7.
3. Rao GV, Reddy N. Transgastric appendectomy in humans. Oral presentation at the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Conference in Dallas (TX): SAGES;2006.
4. Wagh MS, Thompson CC. Surgery insight: natural orifice transluminal endoscopic surgery — an analysis of work to date. *Nat Clin Pract Gastroenterol Hepatol* 2007;4:386-92.
5. Rattner D, Kalloo AN; ASGE/SAGES Working Group. ASGE/SAGES Working Group on Natural Orifice Translumenal Endoscopic Surgery. October 2005 [white paper]. *Surg Endosc* 2006;20:329-33.
6. Khashab MA, Kalloo AN. Natural orifice translumenal endoscopic surgery. *Curr Opin Gastroenterol* 2010;26:471-7.
7. Ryou M, Fong DG, Pai RD, et al. Dual-port distal pancreatectomy using a prototype endoscope and endoscopic stapler: a natural orifice transluminal endoscopic surgery (NOTES) survival study in a porcine model. *Endoscopy* 2007;39:881-7.
8. Scott DJ, Tang SJ, Fernandez R, et al. Completely transvaginal NOTES cholecystectomy using magnetically anchored instruments. *Surg Endosc* 2007;21:2308-16.
9. Lima E, Rolanda C, Correia-Pinto J. Transvesical endoscopic peritoneoscopy: intra-abdominal scarless surgery for urologic applications. *Curr Urol Rep* 2008;9:50-4.
10. Pai RD, Fong DG, Bundga ME, et al. Transcolonic endoscopic cholecystectomy: a NOTES survival study in a porcine model (with video). *Gastrointest Endosc* 2006;64:428-34.
11. Fong DG, Pai RD, Thompson CC. Transcolonic endoscopic abdominal exploration: a NOTES survival study in a porcine model. *Gastrointest Endosc* 2007;65:312-8.
12. Meining A, Wilhelm D, Burian M, et al. Development, standardization, and evaluation of NOTES cholecystectomy using a transsigmoid approach in the porcine model: an acute feasibility study. *Endoscopy* 2007;39:860-4.
13. Mathews JC, Chin MS, Fernandez-Esparrach G, et al. Early healing of transcolonic and transgastric natural orifice transluminal endoscopic surgery access sites. *J Am Coll Surg* 2010;210:480-90.
14. Voermans RP, van Berge Henegouwen MI, Bemelman WA, et al. Feasibility of transgastric and transcolonic natural orifice transluminal endoscopic surgery peritoneoscopy combined with intraperitoneal EUS. *Gastrointest Endosc* 2009;69:e61-7.
15. McGee MF, Marks JM, Jin J, et al. Complete endoscopic closure of gastric defects using a full-thickness tissue plicating device. *J Gastrointest Surg* 2008;12:38-45.
16. Jagannath SB, Kantsevoy SV, Vaughn CA, et al. Peroral transgastric

endoscopic ligation of fallopian tubes with long-term survival in a porcine model. *Gastrointest Endosc* 2005;61:449-53.

17. Merrifield BF, Wagh MS, Thompson CC. Peroral transgastric organ resection in the abdomen: a feasibility study in pigs. *Gastrointest Endosc* 2006;63:693-7.

18. McGee MF, Marks JM, Onders RP, et al.; Case Advanced Surgical Endoscopy Team [CASE-T]. Infectious implications in the porcine model of natural orifice transluminal endoscopic surgery (NOTES) with PEG-tube closure: a quantitative bacteriologic study. *Gastrointest Endosc* 2008;68:310-8.

19. Sumiyama K, Gostout CJ, Rajan E, et al. Endoscopic full-thickness closure of large gastric perforations by use of tissue anchors. *Gastrointest Endosc* 2007;65:134-9.

20. Seaman DL, Gostout CJ, de la Mora Levy JG, et al. Tissue anchors for transmural gut-wall apposition. *Gastrointest Endosc* 2006;64:577-81.

21. Raju GS, Shibukawa G, Ahmed I, et al. Endoluminal suturing may overcome the limitations of clip closure of a gaping wide colon perforation (with videos). *Gastrointest Endosc* 2007;65:906-11.

22. Dray X, Redding SK, Shin EJ, et al. Hydrogen leak test is minimally invasive and highly specific for assessment of the integrity of the luminal closure after natural orifice transluminal endoscopic surgery procedures (with video). *Gastrointest Endosc* 2009;69:554-60.

23. Wagh MS, Merrifield BF, Thompson CC. Endoscopic transgastric abdominal exploration and organ resection: initial experience in a porcine model. *Clin Gastroenterol Hepatol* 2005;3:892-6.

24. von Delius S, Feussner H, Wilhelm D, et al. Transgastric in vivo histology in the peritoneal cavity using miniprobe-based confocal fluorescence microscopy in an acute porcine model. *Endoscopy* 2007;39:407-11.

25. Nikfarjam M, McGee MF, Trunzo JA, et al. Transgastric natural-orifice transluminal endoscopic surgery peritoneoscopy in humans: a pilot study in efficacy and gastrotomy site selection by using a hybrid technique. *Gastrointest Endosc* 2010;72:279-83.

26. Hazey JW, Narula VK, Renton DB, et al. Natural-orifice transgastric endoscopic peritoneoscopy in humans: initial clinical trial. *Surg Endosc* 2008;22:16-20.

27. Kim CY, Chun HJ, Kim JY, et al. Accessibility of peritoneal organs according to the routes of approach in NOTES. *Korean J Gastroenterol* 2008;52:281-5.

28. Akinci D, Akhan O, Ozmen MN, et al. Percutaneous drainage of 300 intraperitoneal abscesses with long-term follow-up. *Cardiovasc Intervent Radiol* 2005;28:744-50.

29. Fulcher AS, Turner MA. Percutaneous drainage of enteric-related abscesses. *Gastroenterologist* 1996;4:276-85.

30. Kumar RR, Kim JT, Haukoos JS, et al. Factors affecting the successful management of intra-abdominal abscesses with antibiotics and the need for percutaneous drainage. *Dis Colon Rectum* 2006;49:183-9.

31. Khurrum Baig M, Hua Zhao R, Batista O, et al. Percutaneous postoperative intra-abdominal abscess drainage after elective colorectal surgery. *Tech Coloproctol* 2002;6:159-64.

32. Fan JK, Lo CS, Law WL. Surgeons' attitudes towards natural orifice transluminal endoscopic surgery. *ANZ J Surg* 2010;80:387-9.

33. Rao GV, Reddy DN, Banerjee R. NOTES: human experience. *Gastrointest Endosc Clin N Am* 2008;18:361-70.

34. Jacobsen GR, Thompson K, Spivack A, et al. Initial experience with transvaginal incisional hernia repair. *Hernia* 2010;14:89-91.

35. Sodergren MH, Clark J, Athanasiou T, et al. Natural orifice translumenal endoscopic surgery: critical appraisal of applications in clinical practice. *Surg Endosc* 2009;23:680-7.

36. Horgan S, Cullen JP, Talamini MA, et al. Natural orifice surgery: initial clinical experience. *Surg Endosc* 2009;23:1512-8.