



Published in final edited form as:

Gastrointest Endosc Clin N Am. 2016 April ; 26(2): 401–412. doi:10.1016/j.giec.2015.12.007.

Pre-clinical Training for New NOTES Procedures: From Ex-vivo Models to Virtual Reality Simulators

Mark A. Gromski, MD¹, Woojin Ahn, PhD², Kai Matthes, MD, PhD³, and Suvrano De, ScD²

¹Division of Gastroenterology/Hepatology, Indiana University School of Medicine, Indianapolis, IN, USA

²Center for Modeling, Simulation and Imaging in Medicine, Rennselaer Polytechnic Institute, Troy, NY, USA

³Department of Anesthesiology, Perioperative and Pain Medicine, Children's Hospital Boston, Harvard Medical School, Boston, MA

Keywords

NOTES; New NOTES; Endoscopic surgery; Simulation; Training

INTRODUCTION

Natural orifice transluminal endoscopic surgery (NOTES) is a relatively new field of advanced endoscopic surgery that has undergone dramatic development and evolution since its inception in 2004 with the seminal description of a transgastric peritoneal access by Kalloo and colleagues.¹ The history of NOTES has been described else-where, and thus is not addressed within this paper.²

Early in the evolution of NOTES, there was a vigorous interest in NOTES approaches to standard and frequent laparoscopic operations, such as the cholecystectomy and appendectomy. Perhaps predictably, given the high standards for safety and efficacy of existing laparoscopic techniques for those common operations, many have not been convinced that moving to a NOTES approach can improve upon the current gold standard laparoscopic approaches. Those traditional procedures are referred to as “first-generation NOTES.” The field in general has pivoted to concentrating research and clinical efforts on novel minimally invasive approaches to pathology within the luminal wall and adjacent to the luminal wall. Peroral endoscopic myotomy (POEM), submucosal endoscopy, full-thickness endoscopic resection (EFTR) of sub-epithelial tumors and peroral pyloromyotomy are examples of this new paradigm, which has been called new NOTES or “near NOTES.”

As with any emerging technology, simulation provides a safe introduction of the technique to the clinic. This is important for new NOTES for several reasons. First, new NOTES procedures requires unique skills that are distinct from standard advanced endoscopic

procedures, such as a requirement to have expertise of trans-luminal anatomy, and mastery in submucosal dissection and various novel endoscopic tools. Furthermore, there needs to be crisp and collegial communication and teamwork between endoscopic and surgical interplay (or backup) for such procedures. Some procedures treat relatively rare pathologic entities (such as achalasia for POEM). Other new NOTES procedures that require submucosal tunneling are born out of endoscopic submucosal dissection (ESD) techniques that were developed in Asia. The training ground is completely different there given the vastly higher number of superficial gastric malignancies that are treated endoscopically there. For these, simulation is critical to supplement low case volumes for new NOTES procedures.

In this review of simulation and training in NOTES, we discuss the importance of simulation in NOTES, describe available simulators and comment on the need for multimodal training. We emphasize developments in ex vivo simulation in new NOTES techniques and also development of virtual reality (VR) NOTES platforms, the 2 most dynamic aspects of NOTES simulation training currently.

OVERVIEW OF NATURAL ORIFICE TRANSLUMINAL ENDOSCOPIC SURGERY SIMULATION

NOTES procedures are universally complex and advanced. They have been developed and studied by world-renowned endoscopists and surgeons, and require exceptional endoscopic skill to be accomplished safely and effectively. Given that NOTES procedures are complex endoscopic tasks that require the development and modification of endoscopic skills that even general experienced endoscopists do not carry, simulation carries an important role in the training environment of NOTES.

Unlike using a novel endoscopic accessory such as a snare that requires little if any specific training before using in clinical practice, NOTES requires mastery of specific skills, such as detailed anatomic understanding, expertise in needle knives and electrosurgery, familiarity with novel endoscopic devices, comfort with closing full-thickness luminal defects and submucosal endoscopy, all of which require practice and dedicated study. The training environment requires repeated skills building with expert guidance, all of which lends well to simulation training.

Available simulation options for NOTES include mechanical simulators including part task trainers to fine tune basic endoscopic skills and full procedure NOTES simulators, ex vivo simulators to simulate entire specific NOTES procedures or components of NOTES procedures (such as full-thickness luminal closure, submucosal dissection), and VR simulators. With recent shifts in interest to new NOTES procedures such as POEM, EFTR, and submucosal endoscopy, the NOTES simulation arena is in a period of development and undergoing changes.

MECHANICAL SIMULATORS

Inanimate task trainers can be used by endoscopists to improve technical endoscopic skills used in day-to-day endoscopy. For endoscopists who wish to learn NOTES, it is absolutely

essential to have mastery of standard endoscopy skills. Inanimate skills trainers can help test and improve those skills. The Thompson Endoscopic Skills Trainer was recently developed as a part task trainer for endoscopists interested in improving or maintaining endoscopic technical skill. The Thompson Endoscopic Skills Trainer is a plastic-based modular portable training center that allows for the endoscopist to perform 5 individual tasks (retroflexion, torque, knob control, polypectomy and navigation/loop reduction) that develop a particular skill used in endoscopy.³ The appealing component of this simulator is that it can provide objective information for skills testing and tracking for trainees. Jirapinyo and colleagues⁴ recently reported a study that confirmed validity of this skills simulator, confirming it can assess endoscopic skills objectively.⁴ Next steps for the simulator included more widespread multicenter trials of trainees skills development and defining learning curves with the simulator.

Mechanical simulators specific to NOTES have been developed. These have been developed for the first-generation NOTES, such as NOTES appendectomy and cholecystectomy. These mechanical NOTES simulators have been reviewed in detail else-where.^{5,6} Two of these simulators are the Endoscopic-Laparoscopic Interdisciplinary Training Entity (ELITE) trainer and the Natural Orifice Simulated Surgical Environment simulator. The ELITE is a plastic phantom developed in Germany, which has previously demonstrated construct validity.^{7,8} There was recently a study reported that used the ELITE NOTES trainer to judge whether previous endoscopic versus surgical simulation training helped novices in performing a simulated NOTES procedures.⁹ The study found that previous training in a simple endoscopy simulator was superior to a laparoscopy simulator to successfully complete a NOTES task in the ELITE simulator.⁹ The Natural Orifice Simulated Surgical Environment is similar to a surgical laparoscopic box trainer and provides skills training for tasks particular to NOTES procedures.¹⁰

A recent study by Buscaglia and colleagues¹¹ used the ProMIS simulator (Haptica, Dublin, Ireland) to carry out simulated transanal NOTES sigmoidectomy procedures. This is a laparoscopic, inanimate surgical simulator that was modified. In this study, 4 participants performed 21 simulated resections, and it was found that the participants had nonsignificant improvements in total procedure time and in 8 individual steps of the operation.¹¹

There has not yet been developed a validated and commercially available mechanical simulator for new NOTES procedures such as POEM or EFTR.

EX VIVO SIMULATORS

A mainstay of simulation in NOTES is the ex vivo simulator. The benefits of ex vivo simulation include the ability to simulate entire NOTES procedures or concentrate on individual tasks (eg, gastrotomy closure); ex vivo simulation is readily commercially available; realistic tissue manipulation is realized given the use of biological tissue, including electrocautery; and ex vivo simulators are relatively less expensive than mechanical simulators, VR simulators, or live animals. Drawbacks of ex vivo simulation include the inability to simulate certain components of a procedure, such as intraprocedural bleeding.

“First-generation” NOTES procedures including intraperitoneal tissue resection (eg, cholecystectomy, appendectomy) can be simulated using total organ porcine explant (Fig. 1) simulators outfitted in specialized simulation trays that simulate an abdominal cavity and allow for both laparoscopic and endoscopic access (EndoSim, LLC, Hudson, MA, USA; Fig. 2).

Furthermore, ex vivo simulators have been created for the simulation of various new NOTES procedures, including POEM, pyloromyotomy, submucosal endoscopy, and EFTR. Simulation sessions can be organized as single complete procedures to introduce the concept of the procedure to endoscopists or to referring physicians. Or, a series of simulation sessions can be arranged to build skills in a certain procedure for the endoscopist who is interested in potentially implementing a procedure into his practice in the future. Particularly helpful are workshops that concentrate on a certain task, such as submucosal tunneling or full-thickness closure (such as endoscopic suturing device or over-the-scope clip; Fig. 3). This allows the endoscopist to add a particular skill to their armamentarium like submucosal endoscopy and full-thickness closure, because these skills are transferrable to a variety of advanced endoscopic procedures.

The effectiveness of ex vivo simulation in advanced endoscopic procedures has been validated. In a group of endoscopists novice to ESD, in which each endoscopist performed 60 each gastric ESD procedures, it was found that there were significant improvements in the speed and quality of ESD resections after 30 cases.¹² Another prospective ex vivo study evaluated the performance of colorectal ESD in endoscopists experienced in gastric ESD yet novice to colorectal ESD.¹³ Each endoscopist performed 30 complete resections. There was significant improvement of performance by each endoscopist in the study. When performance was evaluated with a composite performance score, including time of procedure and complications including perforation, the inflection point of the learning curve appeared after 9 procedures.¹³ Given the complexity of ESD is similar to many new NOTES procedures, it is reasonable to extrapolate that endoscopists would realize similar skills building with other specific NOTES ex vivo simulators. There are studies ongoing to answer this question.

Ex vivo simulators of NOTES procedures can be used to carry out research on clinical questions, as pilot studies before live porcine or human clinical studies. For instance, 1 ex vivo study investigated the maximal diameter of full-thickness gastric defect that could be closed with an over-the-scope clip (Ovesco, Tübingen, Germany).¹⁴ Another study compared the efficacy of gastrotomy closure with different closure devices with either a submucosal tunnel access or transmural gastrotomy.¹⁵ A submucosal tunnel closed with an over-the-scope clip was more secure than either a submucosal tunnel access closed with standard hemoclips or a transmural gastrotomy closed with an over-the-scope clip.¹⁵ Another study used an adult and pediatric ex vivo model for endoscopic pyloromyotomy to investigate the optimal length of myotomy (Fig. 4).¹⁶ In the ex vivo models, the optimal length of myotomy was 3 cm in the adult model and 2 cm in the pediatric model.¹⁶

VIRTUAL REALITY NATURAL ORIFICE TRANSLUMINAL ENDOSCOPIC SURGERY SIMULATORS

A VR-based NOTES simulator is a promising tool, both as a testbed for development of new procedures and instruments and as a training tool for acquiring well-established NOTES techniques and skills. As a testbed, unlike the current paradigm using porcine or cadaver models, a VR-NOTES simulator can provide a fully controllable operating room setting in a safe and risk-free environment without any ethical issues. A variety of scientific techniques used for modeling and simulation can be applied to resolve challenging issues in the field, such as evaluating safe closure techniques and the effects of pneumoperitoneum, before applying them to costly live animal studies or putting human patients at risk. As a training tool, the major benefits include quick and easy setup of various training scenarios, unlimited training materials, and automated, objective, quantitative analysis of surgical skills. Development of a VR-NOTES simulator, however, is a challenging task that requires innovative solutions to hardware and software design. A simulator is only useful if it is shown to be realistic and represent the procedure with sufficient fidelity. In particular, a rapidly developing field such as NOTES requires rapid prototyping technologies to quickly build new high-fidelity simulators for emerging NOTES procedures. To cope with this, our team is developing a VR-NOTES simulator called the Virtual Transluminal Endoscopic Surgical Trainer (VTEST) based on modularization of both software and hardware that facilitates the decomposition of the complex task of developing a new VR-NOTES system into a number of independent reusable and customizable modules.

Fig. 5 shows a schematic diagram of our VR-NOTES simulator that mainly consists of both interface and software components. This standard structure can be applied to build VR-NOTES simulators for the existing and future NOTES procedures in general. A user interacts with the virtual system via the interface that provides an immersive environment as the real operating room. The instruments used on actual NOTES procedures are inserted into the dummy patient that includes realistic natural orifice models, that is, a female reproductive organ model. The instruments are equipped with sensors to measure the motions and motors to provide force feedback to the user. The sensed signal is digitized and sent to the computer. The VR-NOTES software constructs and renders 3-dimensional organ models, and perform numerical computation for simulation of the interaction between the virtual instruments and organ models. The simulated scene is displayed to the user through high-definition display monitors. This is a VR-NOTES simulation cycle looping repeatedly a sequence of the user's hand motions, instrument interface, software computation, displaying the endoscopic view, and force feedback to the user. The system has to guarantee 30-Hz graphic and 1-kHz haptic refresh rates to provide high-fidelity combined sensory feedback. These real-time constraints become more challenging because a high level of visual and haptic realism requires more intensive computation. Thus, it is critical to build the simulation on a well-structured, high-performance software framework.

The VR-NOTES software is based on modular design. The idea is to decompose the complex VR-NOTES software into a number of independent modules. Ultimately, it facilitates rapid development of new simulation for future NOTES procedures by assembling

the already developed modules and customizing them only for the specific requirements. For example, a graphic rendering module that visualizes the internal wall of the stomach and esophagus developed for simulation of transgastric appendectomy can be potentially reused for the development of new simulation for any transgastric NOTES procedures.

The hardware interface of a VR-NOTES simulator consists of modularized subsystems as the software does. The modularized hardware interface provides (1) an insufflated abdominal model with accessible ports (Fig. 6), (2) a rigid endoscope interface (Fig. 7), (3) a flexible endoscope interface (Fig. 8), (4) an interface for laparoscopic instruments, (5) modularized laparoscopic instrument handles, and (6) foot pedals. The hardware modules can be selected according to the requirements of a particular NOTES procedure, assembled with other modules, and integrated into the software module for controlling the hardware. For example, a simulator for pure transgastric NOTES cholecystectomy can be composed of the insufflated abdominal model and the flexible endoscope interface. The obvious benefit of this modular concept is to quickly build new hardware interfaces for new NOTES procedures by customizing the existing modules and assembling a set of the required modules.

The first version of the VTEST in Fig. 9 is being developed based on the transvaginal NOTES hybrid (with laparoscopic assistance) cholecystectomy performed by Roberts and colleagues.¹⁷ The decision to develop a VR-based NOTES training simulator for this procedure was based on a needs analysis at the 2011 Natural Orifice Consortium for Assessment and Research (NOSCAR) meeting.¹⁸ The study found that NOTES cholecystectomy was the most widely performed NOTES procedure at the time and also the most preferred one to be simulated in a VR setting at the time. Also, the trans-vaginal route was preferred over the transgastric approach. The NOTES procedure has unique hand-eye coordination and does not allow bimanual cooperative operation as in traditional laparoscopic surgery. The VTEST is designed to allow surgeons to adapt the new technique and instruments.

The hardware modules are assembled using the dummy patient, rigid endoscope, and laparoscopic interface modules, and integrated into novel software built with female 3-dimensional internal organ models. The transvaginal NOTES hybrid cholecystectomy procedure is divided into 7 sequential tasks based on our task analysis: stabilize gallbladder, identify cystic duct/artery, clip cystic duct/artery, cut cystic duct/artery, detach gallbladder, inspect the operation field, and remove gallbladder with endobag.¹⁹ At the beginning of the simulation, the rigid endoscope is inserted and the tip is placed near the posterior vagina. The extracorporeal suture threads tightly retract the gallbladder for stabilization by assuming that the gallbladder is already stabilized. The trainee can start the simulation by navigating the abdomen cavity to reach the region of interest and performing the subsequent tasks. The simulation ends when the gallbladder is completely detached from the liver bed. Fig. 10 shows simulation screen shots of the successive tasks.

The simulator has been displayed and we have elicited feedback at the NOSCAR meeting annually since 2013.²⁰ We are improving the simulator and planning to perform validation studies to determine the ability to differentiate the level of competence and the

transferability of surgical skills from the simulator to the operating room. Although the VR-NOTES simulator under development is for the cholecystectomy procedure, the VTEST platform can be extended to the simulation of other procedures and techniques using the hardware and software modules. In particular, POEM is identified as a promising candidate for future simulator development from a series of our questionnaire studies at NOSCAR. Furthermore, we are developing automated scoring metrics that will allow real-time assessment of surgical competency. Once completed and validated, we anticipate that VTEST could be used as a training and assessment platform for safe and reliable surgical education.

MULTIMODAL TRAINING IN NATURAL ORIFICE TRANSLUMINAL ENDOSCOPIC SURGERY

The road to performing NOTES procedures in clinical practice at the moment is reserved for experts in advanced endoscopic and endoscopic surgical skills. Both first-generation NOTES and new NOTES procedures require distinct, technologically challenging skills that are often not used in the day-to-day practice of a general gastro-enterologist or surgeon. An inexperienced or poorly prepared endoscopist may have poor results with the adoption of NOTES into clinical practice. For this reason, it is important that those wishing to learning NOTES procedures undergo a multimodal training program to build the necessary skills to successfully perform the procedure of interest.^{2,5} A prototypical training schedule may include initial exposure to the procedure or skills in question with a VR simulator or mechanical simulator. The next step would likely include skills building by performing multiple simulated procedures in an ex vivo model. Next, the training endoscopist should perform procedures in live animal models (most commonly porcine, less commonly canine or sheep), so as to be able to encounter aspects including intraprocedural bleeding and hemodynamic effects of the procedure that cannot otherwise be realistically simulated. At this stage of training, it is ideal to include the entire procedural team, including technician and nurse, so as to familiarize the team with the procedure and tools to be used. The final step of the training paradigm is to undergo proctored, gradual clinical experience with an established expert in the field that performs the procedure regularly.

SUMMARY

NOTES has evolved over the past decade. There is immense clinical and research interest in the current new NOTES procedures, and given the increasing adoption of these procedures here and abroad, this version of NOTES is likely here to stay. With that comes the responsibility to inform health practitioners and effectively train those who may perform these procedures now and in the future.

Given the complexity and distinct skills required of NOTES, simulation will continue to play a prominent role in the training paradigm for NOTES. It is likely that simulation will decrease the lengthy learning curves for these procedures. Simulation research will also continue to advance developmental endoscopy.

References

1. 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. [PubMed: 15229442]
2. Gromski, M.; Matthes, K. Natural orifice transluminal endoscopic surgery (NOTES). In: Jones, DB.; Andrews, R.; Critchlow, J., et al., editors. *Minimally invasive surgery: laparoscopy, therapeutic endoscopy and NOTES*. London: JP Medical Publishers; 2015. p. 199–207.
3. Thompson CC, Jirapinyo P, Kumar N, et al. Development and initial validation of an endoscopic part-task training box. *Endoscopy*. 2014; 46:735–44. [PubMed: 24770972]
4. Jirapinyo P, Kumar N, Thompson CC. Validation of an endoscopic part-task training box as a skill assessment tool. *Gastrointest Endosc*. 2015; 81:967–73. [PubMed: 25310934]
5. Matthes, K.; Gromski, M.; Hawes, R. Training in natural orifice transluminal endoscopic surgery. In: Cohen, J., editor. *Successful training in gastrointestinal endoscopy*. Wiley-Blackwell; 2011. p. 261–9.
6. Gromski M, Matthes K. Simulation in advanced endoscopy: state of the art and the next generation. *Tech Gastrointest Endosc*. 2011; 13:203–8.
7. Fiolka A, Gillen S, Meining A, et al. ELITE—the ex vivo training unit for NOTES: development and validation. *Minim Invasive Ther Allied Technol*. 2010; 19:281–6. [PubMed: 20868301]
8. Gillen S, Wilhelm D, Meining A, et al. The “ELITE” model: construct validation of a new training system for natural orifice transluminal endoscopic surgery (NOTES). *Endoscopy*. 2009; 41:395–9. [PubMed: 19418392]
9. Nehme J, Sodergren MH, Sugden C, et al. A randomized controlled trial evaluating endoscopic and laparoscopic training in skills transfer for novices performing a simulated NOTES task. *Surg Innov*. 2013; 20:631–8. [PubMed: 23493565]
10. Clark J, Sodergren M, Noonan D, et al. The natural orifice simulated surgical environment (NOSSE): exploring the challenges of NOTES without the animal model. *J Laparoendosc Adv Surg Tech A*. 2009; 19:211–4. [PubMed: 19361291]
11. Buscaglia JM, Karas J, Palladino N, et al. Simulated transanal NOTES sigmoidectomy training improves the responsiveness of surgical endoscopists. *Gastrointest Endosc*. 2014; 80:126–32. [PubMed: 24518118]
12. Kato M, Gromski M, Jung Y, et al. The learning curve for endoscopic submucosal dissection in an established experimental setting. *Surg Endosc*. 2013; 27:154–61. [PubMed: 22806508]
13. Gromski M, Saito K, Gonzalez JM, et al. Learning Colonic Endoscopic Submucosal Dissection (C-ESD): a prospective study assessing training using an ex-vivo simulator. *Gastrointest Endosc*. 2014; 79:AB270–1.
14. Matthes K, Jung Y, Kato M, et al. Efficacy of full-thickness GI perforation closure with a novel over-the-scope clip application device: an animal study. *Gastrointest Endosc*. 2011; 74:1369–75. [PubMed: 21981814]
15. Gonzalez JM, Saito K, Kang C, et al. Prospective randomized comparison of gastrotomy closure associating tunnel access and over-the-scope clip (OTSC) with two other methods in an experimental ex vivo setting. *Endosc Int Open*. 2015; 3:E83–9. [PubMed: 26134780]
16. Jung Y, Lee J, Gromski MA, et al. Assessment of the length of myotomy in peroral endoscopic pyloromyotomy (G-POEM) using a submucosal tunnel technique (video). *Surg Endosc*. 2015; 29:2377–84. [PubMed: 25424365]
17. Roberts KE, Shetty S, Shariff AH, et al. Transvaginal NOTES hybrid cholecystectomy. *Surg Innov*. 2012; 19:230–5. [PubMed: 22143750]
18. Sankaranarayanan G, Matthes K, Nemani A, et al. Needs analysis for developing a virtual-reality NOTES simulator. *Surg Endosc*. 2013; 27:1607–16. [PubMed: 23247736]
19. Nemani A, Sankaranarayanan G, Roberts K, et al. Hierarchical task analysis of hybrid rigid scope Natural Orifice Transluminal Endoscopic Surgery (NOTES) cholecystectomy procedures. *Stud Health Technol Inform*. 2013; 184:293–7. [PubMed: 23400173]

20. Ahn, W.; Dargar, S.; Halic, T., et al. Preliminary face validation of a virtual transluminal endoscopic surgery trainer (VTEST). SAGES Annual Meeting; Salt Lake City (UT). April 2–5, 2014;

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

KEY POINTS

The field of natural orifice transluminal endoscopic surgery (NOTES) has evolved over the past decade. There is immense clinical and research interest in the current new NOTES procedures, and this version of NOTES is likely here to stay. With that comes the responsibility to inform health practitioners and effectively train those who may perform these procedures now and in the future. Given the complexity and distinct skills required of NOTES, simulation will continue to play a prominent role in the training paradigm for NOTES.

It is likely that simulation will decrease the lengthy learning curves for these procedures. Simulation research will also continue to advance the developmental endoscopy field.



Figure 1.
Abdomino-pelvic porcine tissue explant arranged for first-generation NOTES procedure.

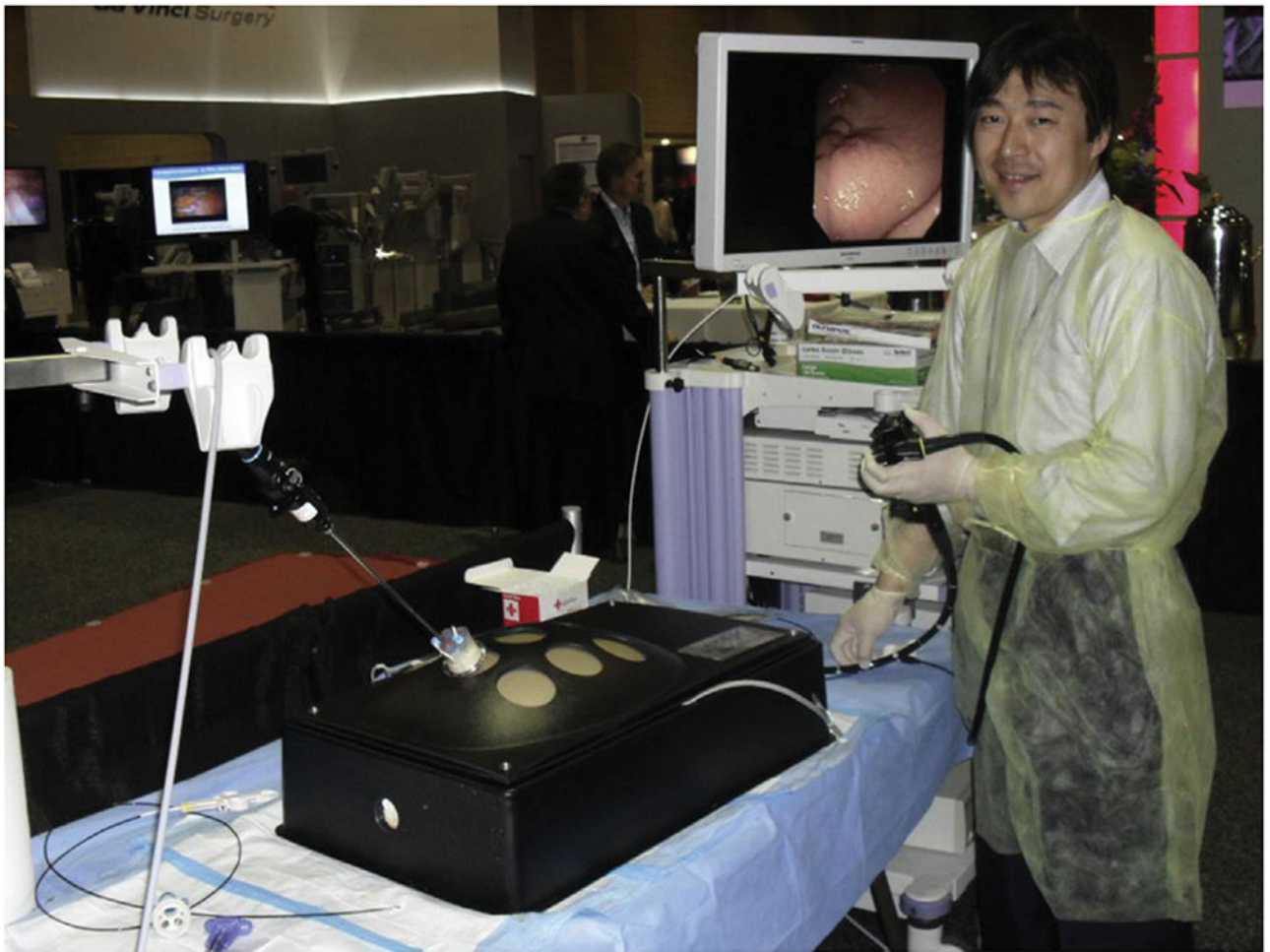


Figure 2. Endoscopist training in an ex-vivo simulator allowing for laparoscopic visualization of endoscopic procedure.



Figure 3. Gastrotomy closure with over-the-scope clip (Ovesco, Tübingen, Germany) in an ex-vivo model.

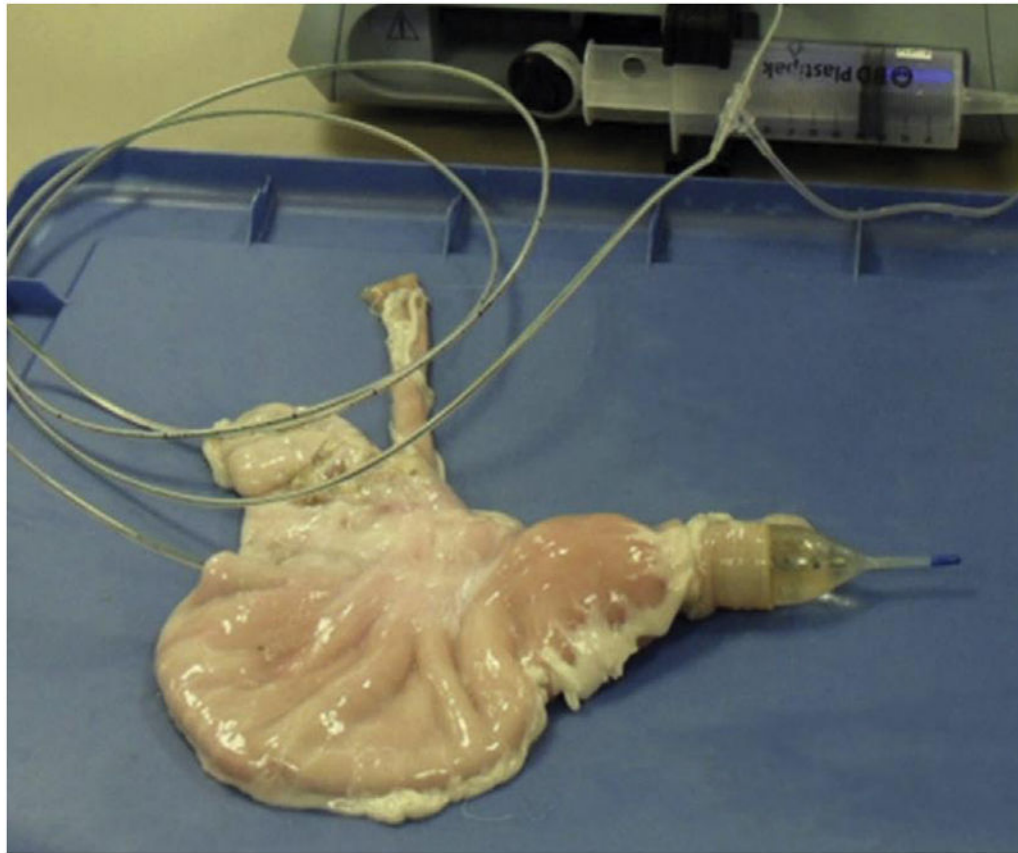


Figure 4. Ex-vivo simulation model for endoscopic pyloromyotomy, measuring the effectiveness of myotomy with EndoFlip (Crospon, Galway, Ireland).

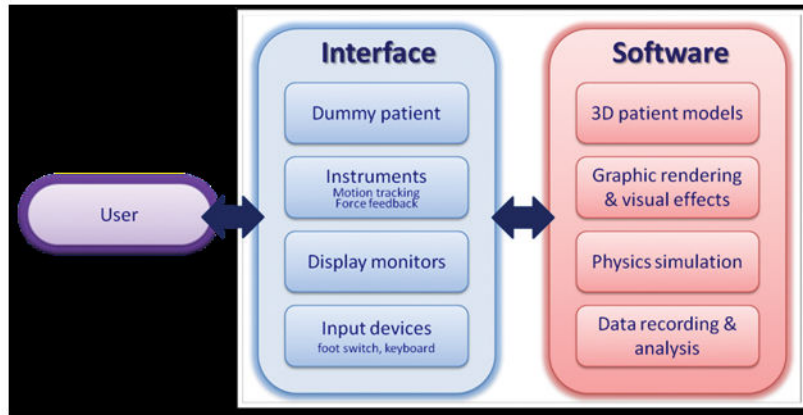


Figure 5. Diagram of the virtual reality natural orifice transluminal endoscopic surgery simulator

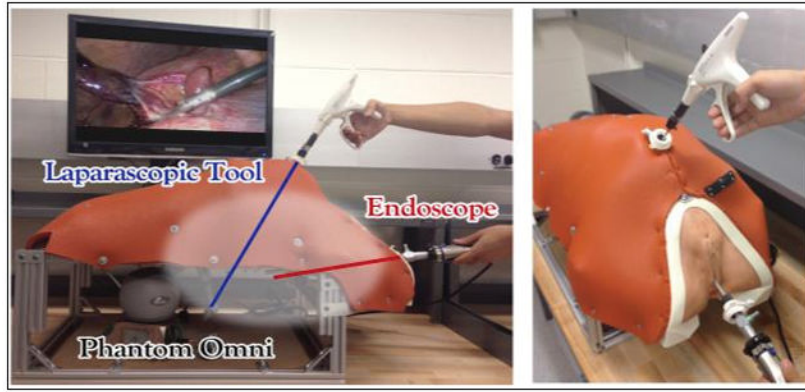


Figure 6. A dummy patient for the virtual reality natural orifice transluminal endoscopic surgery simulator

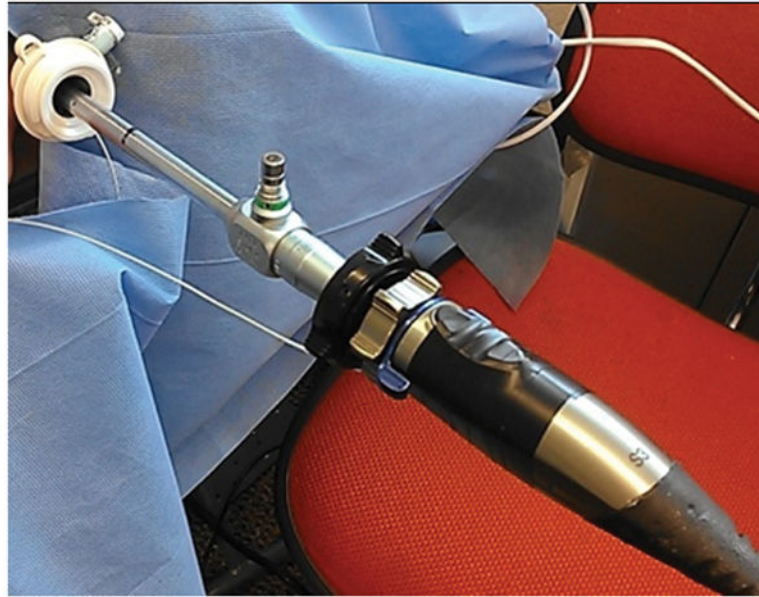


Figure 7.
Rigid endoscope interface.

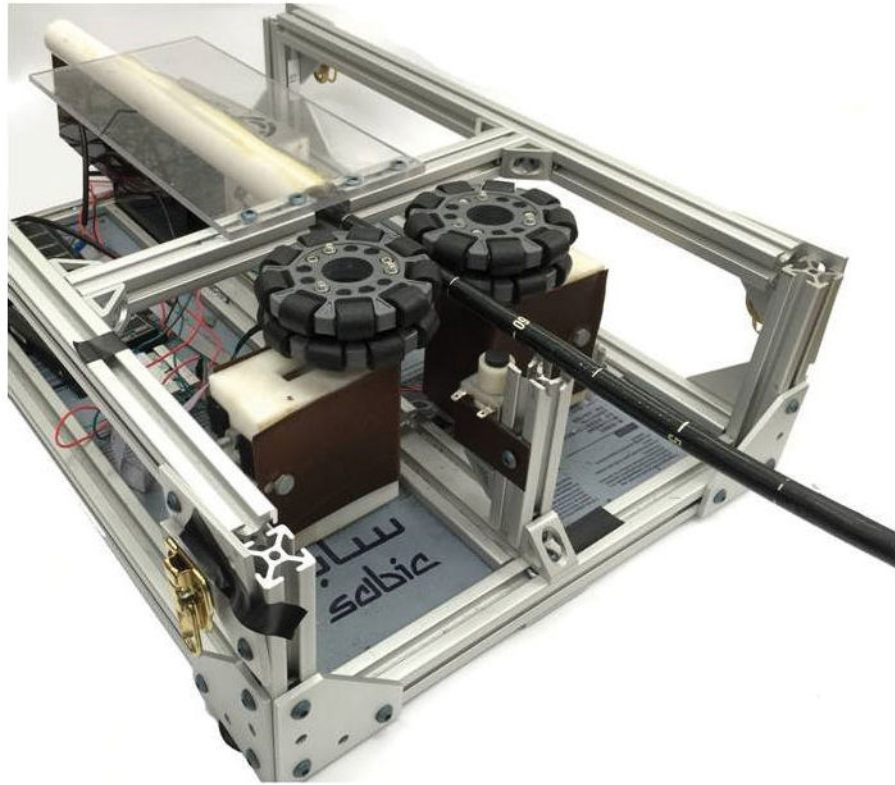
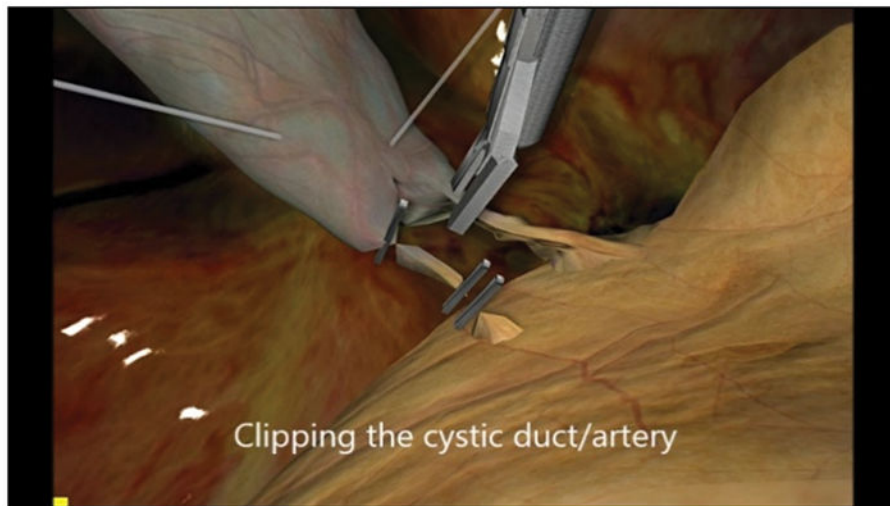
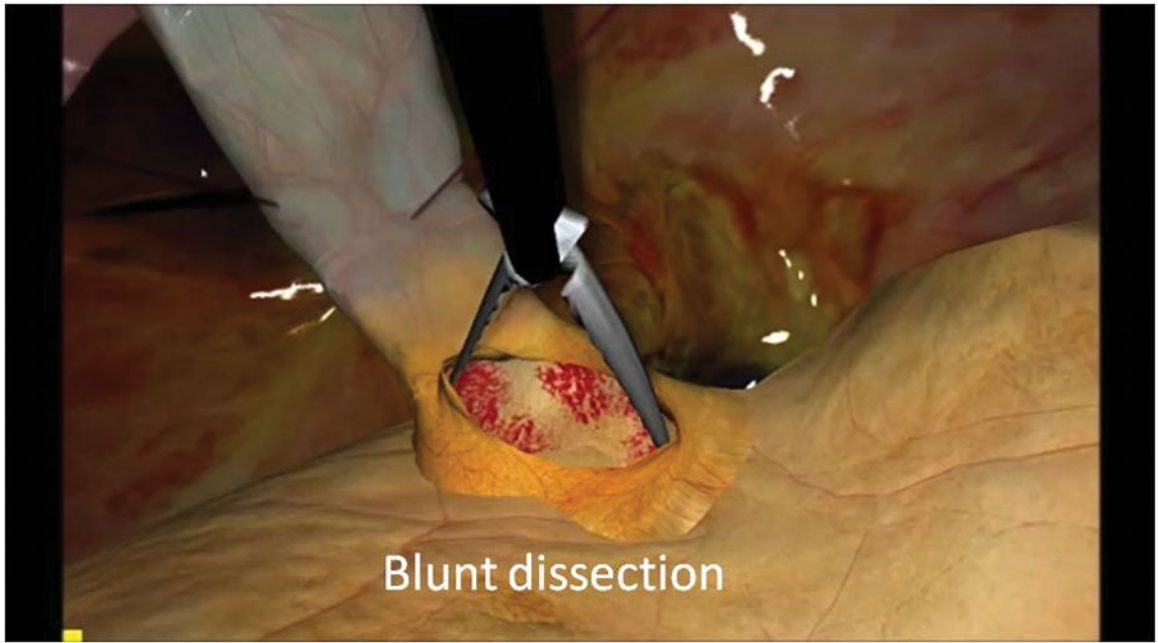


Figure 8.
Flexible endoscope interface.



Figure 9.
A virtual simulator for hybrid transvaginal NOTES cholecystectomy.



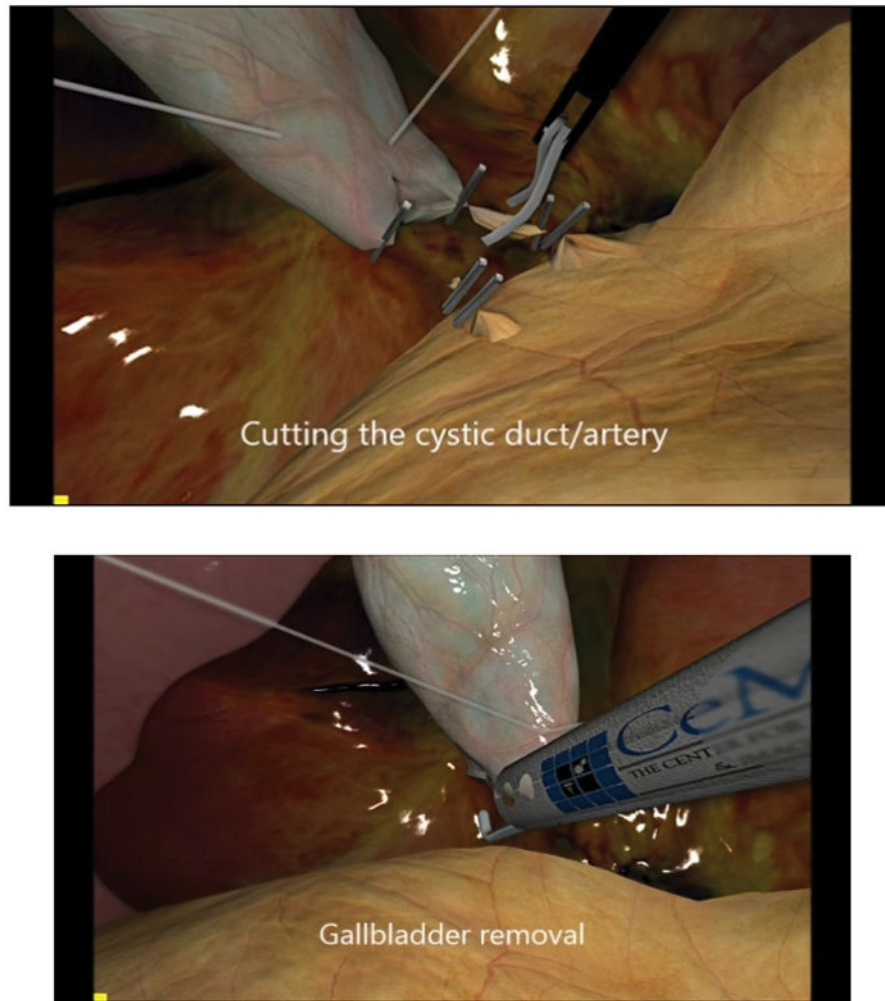


Figure 10. Simulation scenes in virtual reality natural orifice transluminal endoscopic surgery cholecystectomy: a.) blunt dissection, b.) clipping of the cystic duct/artery, c.) cutting the cystic duct/artery, d.) gallbladder removal.