# Endoscopic Surgical Platforms

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## 22.1 Introduction

With the development of advanced minimally invasive therapy, the role of endoscopic involvement in therapeutic procedures in the gastrointestinal (GI) tract has substantially increased [1–11]. The trend of minimizing access trauma has stimulated gastroenterologists and surgeons to use interventional endoscopic technology to replace a number of procedures, which were a mainstay in open surgery and even some in laparoscopic surgery [2, 5, 7, 8–11]. The more these procedures require sophisticated steps, the more traditional endoscopes will reach a limitation in their technical abilities. One can be surprised that using the traditional endoscopic technology – designed half a century ago for diagnostic purposes – was able to be utilized for effective endoscopic hemostasis, perform tumor resections in the gut, treat gastroesophageal reflux disease, and get involved in bariatric procedures [7–9]. These procedures are made possible by a number of specially developed endoscopic tools, mainly based on commercially available, flexible endoscopes [5–9].

During the introduction of natural orifice transluminal endoscopic surgery, a number of endoscopic and surgical platforms emerged from different companies and institutions [3–5]. These platforms seemed to become major "game changers" for intra-abdominal surgery using a transgastric route [12–14]. However, today we know that these ideas were premature to make it into clinical practice. It was too early for the readiness and willingness of the most important industrial players to further invest, develop, and provide sophisticated platforms necessary to put these disruptive ideas into clinical practice together with the medical community [12, 13].

There were a few exceptions [14, 15]. Many involved parties have learned that this interruption in development does not lower the value of some of these highly advanced technologic ideas. These platforms for improved endoscopic surgery in the gastrointestinal tract using a combination of flexible endoscopic and laparoscopic paradigm and technology are still needed [4, 5, 12–18]. One may ask what exactly an "endoscopic surgical platform" should be and what characteristics this system must fulfill to qualify for such a description.

An endoscopic surgical platform (ESP) should be able to maneuver within the gut with its intraluminal restrictions and at the same time carry the potential to be used for basic surgical tasks such as cutting, dissecting, traction, and countertraction, as well as suturing.

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S. Horgan, K.-H. Fuchs (eds.), *Innovative Endoscopic and Surgical Technology in the GI Tract*,
https://doi.org/10.1007/978-3-030-78217-7_22

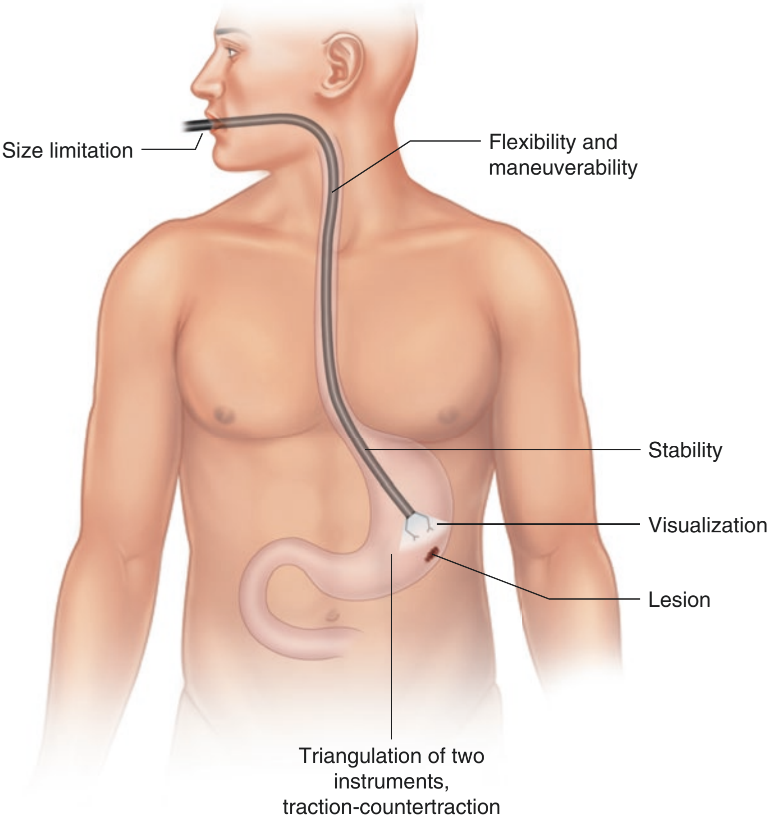
## 22.2 Prerequisites and Limitations of Endoscopic Surgical Platforms

There is a *size limitation* in the GI tract for instruments, which accounts especially for procedures in the upper GI tract with an esophageal diameter at a maximum of around 2 cm. The latter requires a platform size of a diameter below this borderline as a prerequisite for clinical use (Fig. 22.1).

Another prerequisite is the *visualization* of the anatomical region of interest (target area) combined with the need for the precise application of instruments under visual control. This level of visualization can be implemented by all modern commercially available endoscopes in a high quality.

*Triangulation* is important in surgical manipulations and should be possible with these platforms (Fig. 22.1). A rather simple way of providing some degree of triangulation was implemented in the dual-channel endoscopes. Triangulation was possible by modifying the working channels and their distal exit at the tip of the scopes for endoscopic instruments with an Albarran-steering lever, with which one can modify the direction of these instruments. This allowed for steering the endoscopic tools through the working channels. A movement regarding their axis toward the target organ, for example, moving an instrument up-and-down or side-to-side is possible. As a consequence, one could use a grasper in a slightly different axis causing some traction and use the other instrument for dissec-

**Fig. 22.1** Schematic overview of the important features on an "ideal" endoscopic platform for intraluminal and transluminal endoscopic surgery: the requirements concern size limitations, visualization, triangulation, both stability and mobility, sufficient force to drive the end-effectors, independence of visualization, and precision in end-effector manipulation



tion. However, there would be no complete independency between visualization and action of the end-effectors.

For surgical actions at the tissue level, a triangulation of at least two instruments in the target area is needed to perform normal surgical maneuvers such as cutting, grasping, and suturing. Endoscopists with a gastroenterlogy background may argue that they do not need triangulation to perform interventional endoscopy, which they have proofed many times. However, a performance of more sophisticated surgical procedures, especially those where traction and countertraction as well as surgical dissection in "defined tissue layers" is needed, would require a full set of surgical tools. This is especially true for routine surgical suturing, safe adaptation of anastomoses, and tissue closure.

Sufficient *stability and mobility* of the endoscopic surgical platform is another prerequisite to perform precise maneuvers of the end-effectors at the tissue level (Fig. 22.1). This requires, on one hand, a maneuverability of the complete platform to move in and out of the GI tract and back and forth to advance toward the target area. On the other hand, the platform must have a feature to "freeze" in a stable position to apply a strong retraction and countertraction and/or to enable the "frozen platform" to serve as a basis for "high-precision" movements of its end-effectors to perform surgical manipulations at the tissue level in the "target area."

An important prerequisite is the *force* that should be translated from the handles to the end-effectors by moving steering handles from the outside of patients. The earliest attempt to use a special endoscopic platform for suturing was the Endo- Cinch™ system, using a suturing device mounted on a flexible scope [19]. This technology was initially used for the treatment of gastroesophageal reflux disease in narrowing the cardia [19, 20]. Unfortunately, the sutures could only be placed quite superficially into the mucosa rather than a necessary "deep bite" through the muscle of the lower esophageal sphincter, and therefore, this technique was only partially successful in treating gastroesophageal reflux disease [20, 21]. This highlights a problem of a flexible endoscopic platform in lacking substantial force at the end-effector level because of the otherwise necessary flexible shaft to overcome the distance between the external manipulation site of the platform (at the mouth) and the target area, for example, in the stomach.

Another limitation in using an endoscopic surgical platform efficiently is the lacking *independence* between the visualization and the end-effector maneuvers (Fig. 22.1). Often, these two functions are combined in the hardware, which limits the overview and precise manipulation of the instruments as the experience shows in early prototypes of endoscopic surgical platforms. When performing precise surgical maneuvers with the end-effectors, a good overview on the complete target area as well as the surrounding organs is required to fulfill some tasks safely. If the vision is limited because the visual window is moved in a wrong direction following only one end-effector, since they are mechanically connected, optimal overview is destroyed or at least reduced. Therefore, an independence of these two functions is advisable.

In addition, this also limits the ability of efficient intra-abdominal control for safety during the procedure. The latter will have its influence on the limitation of the necessary *precision* of end-effector movements and maneuverability.

## 22.3 The Development of Endoscopic Platforms

Endoscopic suturing has been around for almost 20 years. Early suturing was performed by Bard EndoCinch™ (USA) with limited success since the force and depth of the suturing bites in the gastric wall were insufficient [19–21]. Another promising project was the Olympus prototype Eagle Claw, which seemed to provide abilities for deeper bites, but remained a prototype. Eventually this prototype was taken over by Apollo Endosurgery, Austin, TX, USA [22–25]. This company modified it into a commercial product, which is successful on the market and used quite frequently (OverStitch, Apollo Endosurgery) (Fig. 22.2) [13, 23–25]. In addition, the concept

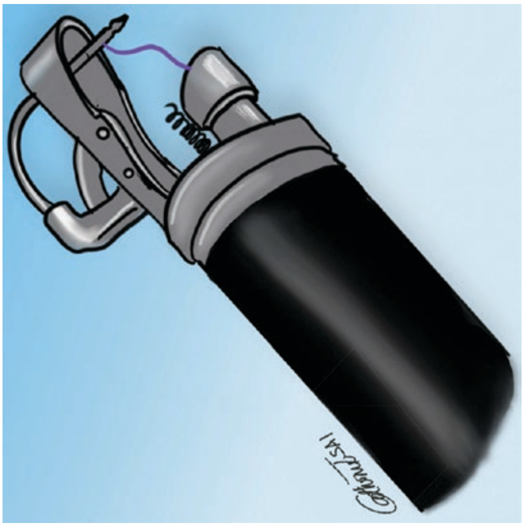


**Fig. 22.2** Scheme of the OverStitch endoscopic suturing system, which allows for an application of a needle through both rims of a lesion to adapt and close it by a sufficient suture and knots

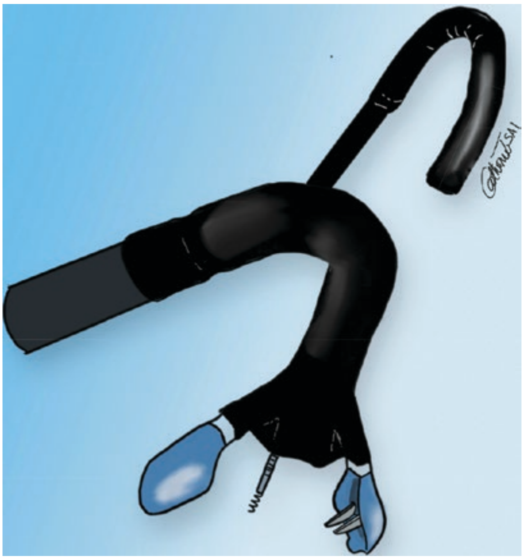


**Fig. 22.3** Scheme of the "Plicator," which came on the market initially as therapeutic tool for creating a gastroplication, a fundic fold to augment the lower esophageal sphincter. It has two strong branches for establishing a sufficient suture through the gastric wall.

of T-bars was introduced (Wilson-Cook, NC, USA), but did not succeed in the market.

More effective than the first suture device was the "Plicator," which was able to perform deep sutures in the gastric wall, simulating a plication of the fundus (Fig. 22.3) [3]. This concept was later taken over by GERDX™ (G-Surg, Seeon-Seebruck, Germany). GERDX™ is a device with sufficient depth in suturing to plicate the fundic wall from intraluminally to create a sufficient gastroplication [3, 12, 26].

The current GERDX™ system and the Apollo OverStitch™ system are those systems with a reasonable spread in clinical use. The Apollo OverStitch™ system has been used widely for flexible endoscopic suturing and closure of perforations in clinical routine (Fig. 22.2). Several authors report on the success of this method requiring training and a dedicated team [13, 23–25].

Specially designed flexible endoscopic instruments with more surgical character were developed such as a Maryland dissector to manipulate tissue with more force than a regular endoscopic grasper and scissors with larger blades similar to laparoscopic scissors (Ethicon, Cincinnati, USA). These instruments had joints in their shaft for angulation and improved mobility for intraluminal and intra-abdominal applications (Fig. 22.4). The handling of these instruments was adapted to a more surgical use. Laparoscopic surgeons were used to handles with a laparoscopic paradigm. Endoscopists usually use flexible endoscopic instruments with a completely different design of instruments and handles [27]. As a consequence, the optimal handles depend on the function of the instrument and on the educational and training background of the team that is using these instruments.

## 22.4 Specialized Endoscopic Surgical Platforms

Initially, some intraluminal devices could be used for special indications such as suturing or adaptation, but a stable platform was lacking. An early company to focus on special instruments for natural orifice surgery was USGI Medical (San Capistrano, CA, USA), focusing on the stability of an endoscopic system within the gastric lumen to perform more sophisticated maneuvers [14].

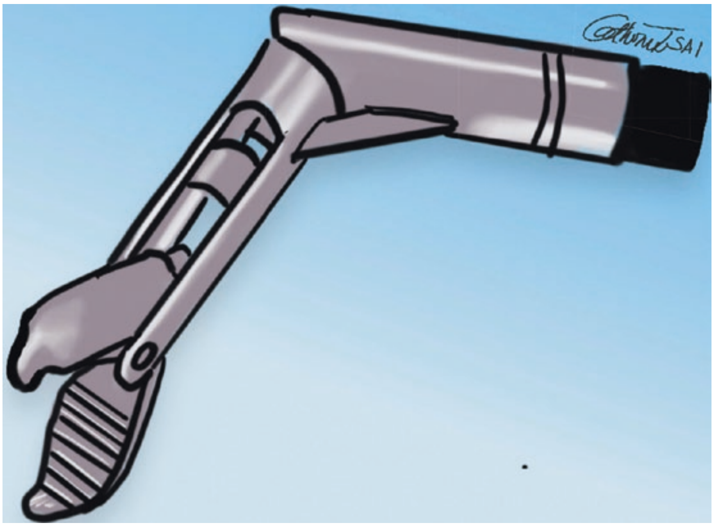


**Fig. 22.4** A grasper with integrated joints (Ethicon-toolbox instruments), allowing for angulation of the end-effectors, which enabled very precise manipulations of these instruments at the tissue level in the target area.

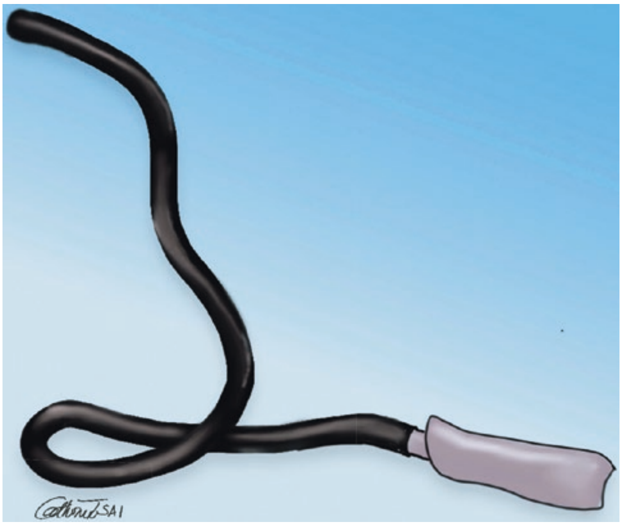


**Fig. 22.5** Scheme of the “shapelock” system by USGI, an access system for the use with commercially available endoscopes and special instruments. The system provided more stability of the endoscope and therefore more precision of the end-effectors at the tissue level.

This company developed an access system for the use with commercially available endoscopes and special instruments from this company. One special instrument was the “shapelock” system for flexible scope and endoscopic instruments (Fig. 22.5).

This system can be stiffened, while carrying an interior “daughter scope,” which subsequently could be fixed in its position to perform dedicated endoscopic surgical tasks via the endoscopic tools, which are brought in via the working channels. Several ports were connected with the shaft to carry endoscopic and surgical flexible instruments. The system could be inserted like a regular endoscope into the gut. Furthermore, the system could be locked (stiffened) into a position at the target area to perform more delicate surgical maneuvers. One prototype was developed for suturing (9-Prox USGI Medical, USA).

A true multitasking platform for endoscopic surgical procedures was the Cobra system (USGI Medical, USA) (Fig. 22.6). In this prototype device, the request for triangulation of instruments is implemented perfectly since three instrument arms are established for surgical maneuvers [14, 28]. Others have used a similar

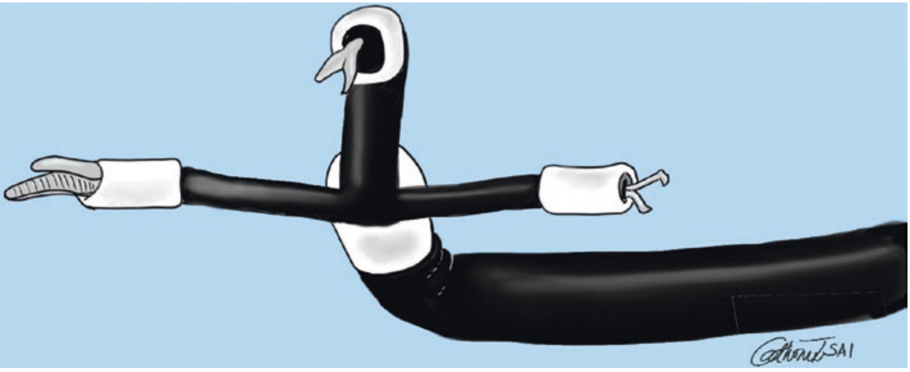


**Fig. 22.6** Scheme of the USGI-Cobra system, one of the first multitasking platforms to perform surgical manipulations with triangulation with a flexible endoscopic tool. It contained several features to work intra- and transluminally.

device [15]. Again, a 6mm flexible endoscope can be used through the channels of the system. Under visual control of the endoscope, the system can replicate "laparoscopic-like" maneuvers such as dissection and suturing. Another advantage of the system was the possibility to achieve some traction and countertraction.

The transformation of forces and manipulations for the end-effector movement was realized by mechanical system. While complex movements of manipulation were quite possible, suturing was difficult because of the lacking strength and translated force on the arms. Also, knot tying remained quite troublesome.

This platform was designed for intraluminal and also intra-abdominal applications using either a transgastric or the transrectal route. With a diameter of 15 mm, it was quite easily possible to advance this system through the esophageal lumen into the stomach, where it could be used to penetrate the gastric wall, and after further advancement, one was able to perform intra-abdominal surgery.

Another endoscopic surgical platform was the EndoSAMURAI™ (Olympus Corp., Tokyo, Japan), which was tested and investigated between 2007 and 2011 to assess the feasibility of surgical procedures [16, 29]. The endoscopic surgical system consisted of an endoscopic shaft with a traditional endoscopic steering unit, connected to an interface that can be used as "laparoscopy-like" working station to perform the surgical maneuvers (Fig. 22.7).

At the tip of the flexible endoscope, two working arms were connected, which have working channels for the end-effector instruments, brought out for surgical manipulations. The two articulating working arms could be moved out of the original diameter of the scope and therefore provided more triangulation with an elbow-like function, which could be deployed within the lumen of the gut or within the abdominal cavity. The shaft of the endoscope was connected to a traditional steering unit of the endoscope at its proximal end and a mechanical connection to a separate working station, from which an operator could manipulate the end-effectors. The endoscopic control mechanism was operated by an endoscopist (Fig. 22.7).

A surgeon operated the work station with a laparoscopic paradigm using bimanually manipulations, which could be observed on a video screen. The laparoscopic workstation mechanically transmitted the motion of the handles of the effector instruments to the tips of the end-effectors that were advanced through the flexible working channels into the working arms. The system is similar to a traditional endoscope a light source and insufflation. There are also standard functions for suction and possibility of rinsing the endoscopic lenses. This system consists of a classic endoscopic component, which is launched via a natural orifice in the body and a laparoscopic work station unit, that can be operated with laparoscopic surgical abilities. Therefore, the system is operated best by two

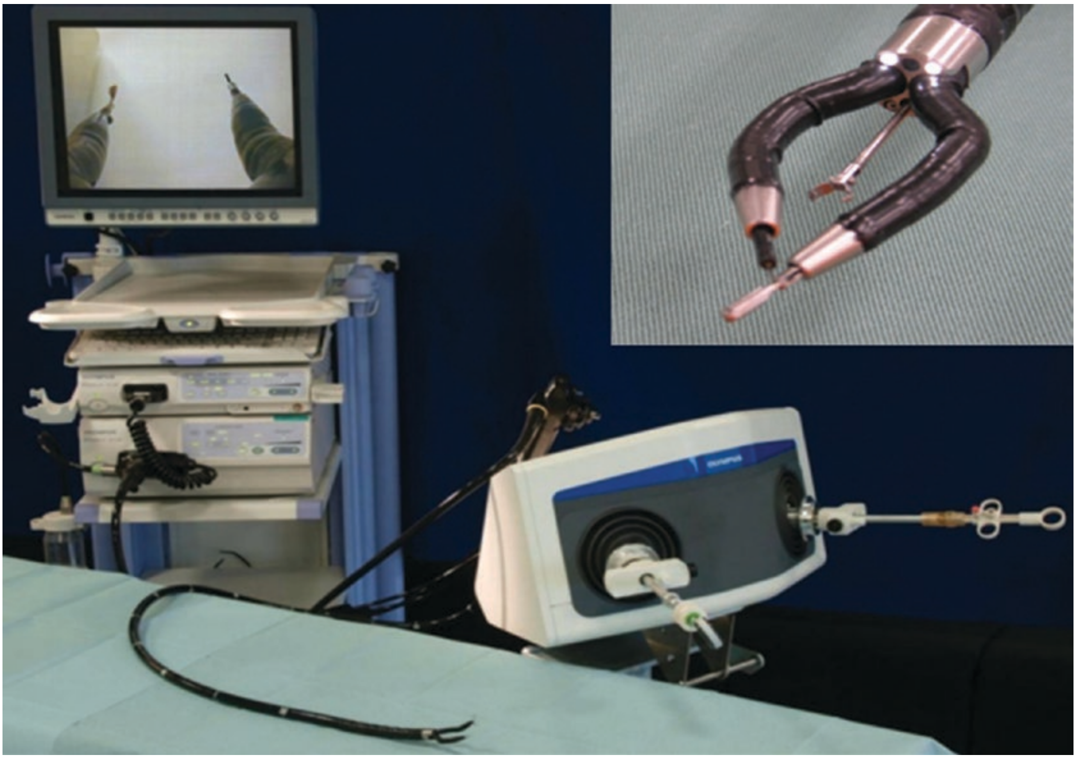


**Fig. 22.7** EndoSAMURAI™ (Olympus Corp. Tokyo, Japan), an endoscopic platform with a laparoscopic paradigm. A surgeon can use a workstation to manipulate handles, which will steer end-effectors via a flexible endoscope intraluminally and transluminally. An assisting endoscopist handles the necessary manipulations of the flexible endoscope.

individuals; on one hand, the active surgeon at the work station, and on the other hand, a camera assistant, who is responsible for the general maneuvering of the tip of the endoscope as well as the in–out movements of the endoscope in order to advance or withdraw the endoscope within the gut and/or in the abdominal cavity. Exchangeable instruments via the working channels of the scope allow for a variety of applications of the working arms such as grasping, retracting, tissue cutting, coagulation, hemostasis, as well as suturing with a needle holder. The stability of the platform was ensured by the rigidity of the steerable overtube.

Training experience was established and published [16]. This consisted of Box-training and training in the animal laboratory for small bowel resections. This endoscopic surgical system serves well as a multifunctional endoscopic platform for the use of transgastric small bowel resection and anastomosis (Fig. 22.8).

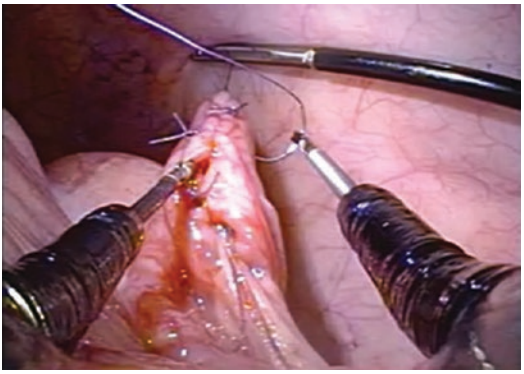


**Fig. 22.8** The completion of a bowel anastomosis is possible with the EndoSAMURAI™ platform by suturing the anastomosis in a classical surgical way with needle holder and grasper. The system had sufficient stability and force as well as precision in movements to complete these tasks.

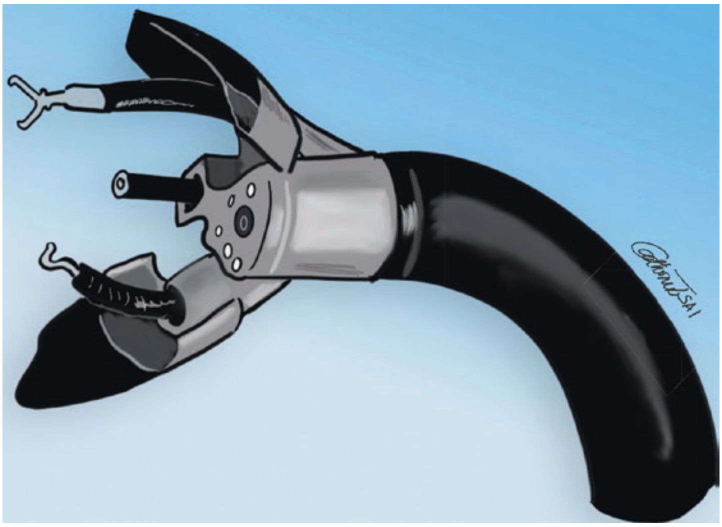


**Fig. 22.9** Scheme of the Karl Storz Anubiscope™ system, a platform for intraluminal and extraluminal endoscopic surgical tasks. The system can be used for dissecting, retracting, and suturing.

A similar development is the Anubiscope™ (Karl Storz, Tuttlingen, Germany) (Fig. 22.9) [17]. In this system, a flexible endoscopic carrier with endoscope technology has also several working channels for flexible surgical instruments and steering mechanisms to maneuver these instruments at the target area [17]. The manipulation of the instruments can be done by two mechanisms: (1) by the tip design of the carrier endoscope with two triangulating arms that can be opened, thus manipulating the flexible instrument through the working channels, and (2) by flexible instruments that are advanced through the working channels of the carrier, being steered from the external handle of the instruments.

The system allows for working within the gut and transluminal also in the abdominal cavity once the carrier is penetrated through the gastric wall [17]. The tip of the sophisticated carrier endoscope is quite blunt and needs an incision to penetrate through the gastric or colon wall. Once the carrier endoscope is positioned at the target area, special flexible instruments with a surgical character can be moved with independent motion. A certain drawback is the necessity of two endoscopists cooperating very closely together. One endoscopist operates the necessary maneuvers of the carrier endoscope, and the other endoscopist operates two flexible endoscopic instruments through the working channels of the carrier. The two endoscopists must work together at a high level to coordinate the necessary maneuvers and procedures. This platform has been used in clinical cases [17]. Since the closed tip of this endoscopic carrier is quite blunt, there is no need for an overtube to pass through the pharynx into the esophagus. However, the maneuverability is limited in a narrow and intraluminal channel.

Other similar platforms were developed such as the prototype Direct Drive Endoscopic System (Boston Scientific, DDES™) [15].

## 22.5 Robotic Endoscopic Surgical Platforms

Meanwhile, robotic technology has been introduced in endoscopic and surgical concepts [30–34]. More advanced systems are based on robotic technology such as the “Master-and-Slave Transluminal Endoscopic Robot (MASTER)” from the University in Singapore [35]. This system is a conventionally cable-driven manipulator with combined robotic technology, providing a six-degree freedom of motion at the end-effectors, which is excellent for precise maneuvers at the target area (Fig. 22.10) [35, 36].

It is associated with a regular endoscope. It requires two operators/endoscopists. In the past 10 years, several publications report on the experience with this system [35, 36]. However, unfor-

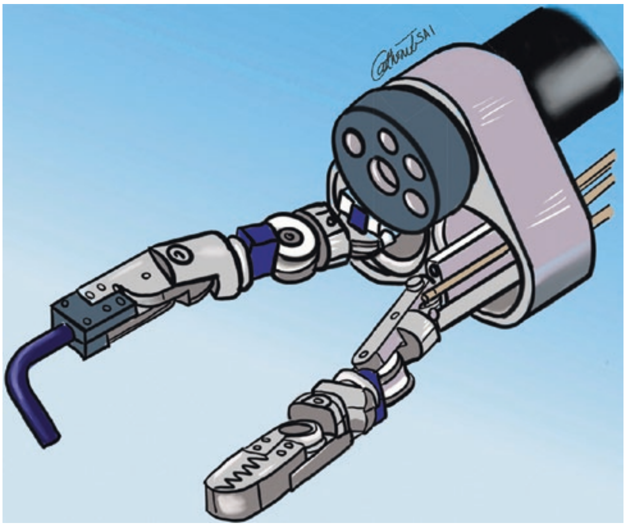


**Fig. 22.10** The “Master-and-Slave Transluminal Endoscopic Robot (MASTER)” is a system with a conventionally cable-driven manipulator with combined robotic technology, providing a six-degree freedom of motion at the end-effectors. Complex surgical procedures are possible.

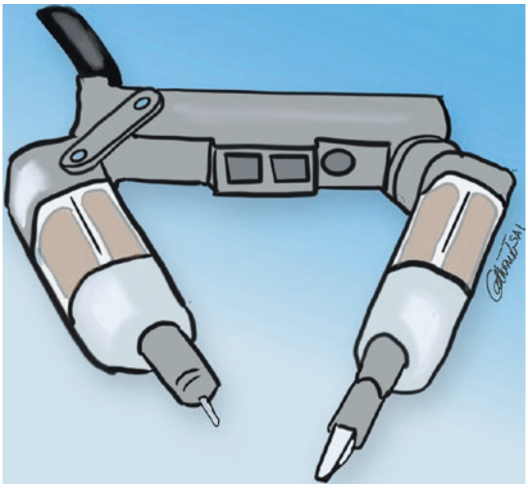


**Fig. 22.11** The scheme of the future of robotic technology may be envisioned with this device, a miniature robotic system, which is small enough to be advanced through a trocar into the abdominal cavity. Once inside the abdomen, the miniature robot can angulate its arms to create some triangulation with two mechanically active arms.

tunately the systems have not reached a routine clinical application.

An even more sophisticated and futuristic system is an intraperitoneal miniature robot developed by the University of Nebraska (Fig. 22.11) [37, 38]. The concept of this device is an application of miniature robotic system, which can be advanced through a trocar into the abdominal cavity. Once inside the abdomen, the miniature robot can angulate his arms to create some triangulation with two mechanically active arms for surgical manipulations, steered via remote control from outside the body [37, 38].

## 22.6 Future of Endoscopic Technology

Facing a meanwhile 15-year-long, rather unsuccessful history of endoscopic platforms, the costs of complicated mechanical and also robotic-based technologies seem to have one drawback, which is hard to overcome: the unrealistic costs. As a consequence, there has been a recent reflection on more simple, mechanical systems, which may be more realistic to develop than complex robotic systems [38–45].

An “easy-to-use” mechanical manipulator platform may be developed in reasonable time with reasonable costs without major investment for a hospital, which may be a more attractive alternative for industry and others [43–45]. As a consequence, if modern tools can be developed, which can be applied through commercially available endoscopes without major additional investments, this concept may be more realistic in times of financial constraints in medicine. Furthermore, flexible endoscopic instruments are following currently still the size limitations of a narrow working channel on endoscopes,

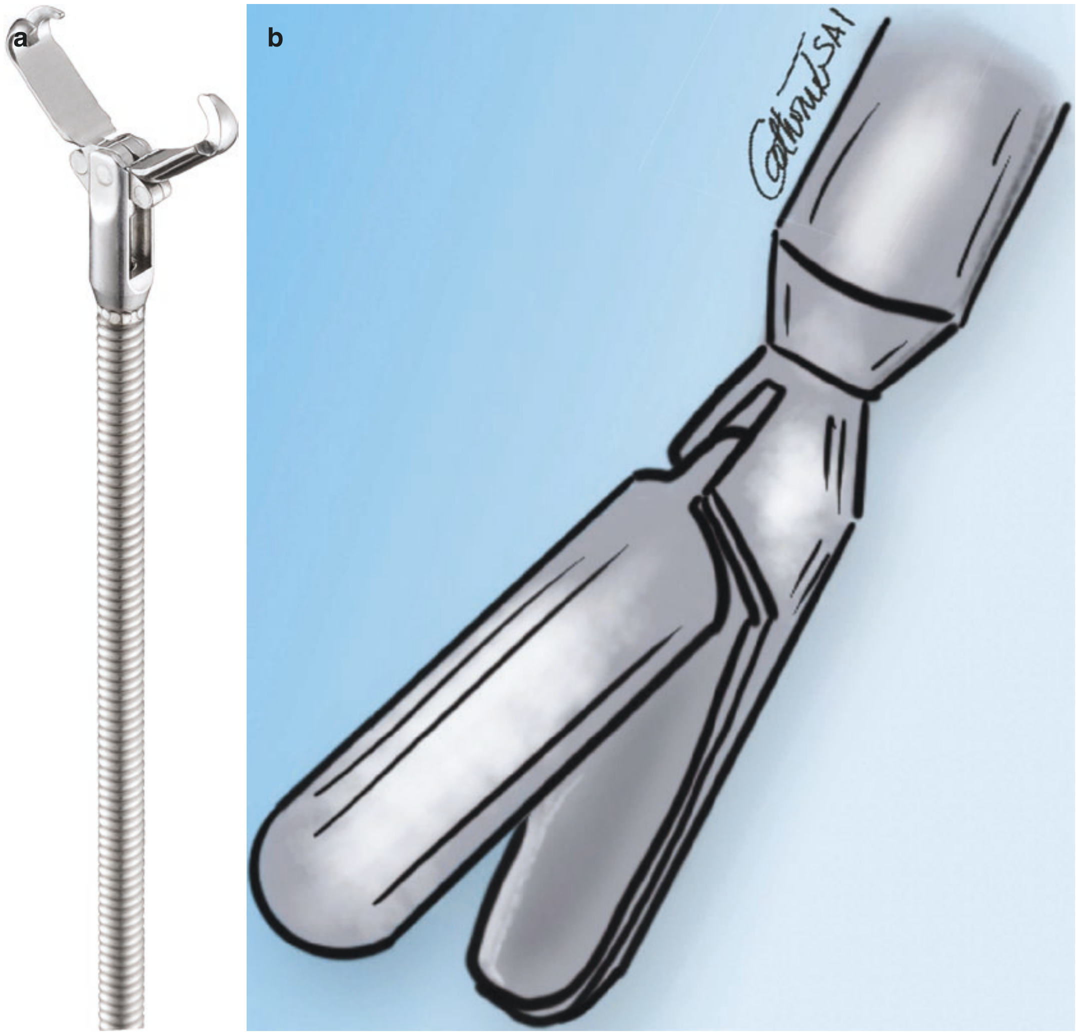


**Fig. 22.12** (**a**) Endoscopic grasping device with a small "mouth" (Olympus Deutschland, Hamburg) (small grasping branches, which may be insufficient in traction, but great for biopsies; (**b**) laparoscopic grasper with large branches for traction, which is also needed in flexible endoscopic surgical manipulations. A combination of these thoughts and needs, built in one flexible endoscopic tool, would fulfill unmet needs.

designed originally for diagnostic purposes. A new approach could be to integrate surgical principles in their structure and functionality. A simple example are graspers, which usually follow the flexible endoscopic paradigm of rather small grasping branches, which may lack sufficient power and force of holding to a structure to create enough traction and countertraction (Fig. 22.12a, b). The vast experience in laparoscopic surgery with graspers with longer branches and differentiated surfaces for certain functions may be worthwhile to explore to improve tissue handling (Fig. 22.12b). These could be small steps with substantial effect in moving endoscopic technology forward. Recent endoscopic research is aiming exactly in this direction [46–49].

The principle of minimal access surgery is the reduction of access size and access trauma. The clinical aims are a shorter patient recovery, improved postoperative well-being, better cosmesis, less inhibiting postoperative restrictions in order to get the patient quickly back to full physical and psychological abilities, and possibly an improved long-term outcome. The latter could be achieved by less wound infections and less incisional hernias over time. The advantage of this concept of minimal access surgery over conventional open surgery has been clearly shown in the past decades.

Whether a further reduction in access trauma can improve the patient's outcome even further has been difficult to prove in the past years. This goal can be reached in two ways. One direction is the development of new technology to facilitate certain necessary surgical steps for endoscopic techniques with endoscopic surgical platforms as pointed out in this chapter. From the surgical standpoint of view, a system is needed that can be transported via the abdominal wall or a natural orifice with a limited diameter into the abdominal cavity, where all surgical functions can be applied such as visualization, traction and countertraction, dissection, hemostasis, and suturing. Robotic technology may enable the desired needs [39–42].

Another approach is the transformation of therapeutic ideas from a surgical concept into an endoscopic concept. An excellent example for this is peroral endoscopic myotomy since the central therapeutic concept of myotomy is kept, but the approach is transferred from a transabdominal pathway to a pure endoscopic transesophageal pathway [4–6].

Further developments in endoscopic, surgical, multifunctional platforms are necessary in the future. Optimal multitasking platforms should have changeable end-effectors, image guidance, possibility of traction and countertraction, as well as sufficient triangulation and at the same time steerable stability to increase precision in manipulations.

## References

1. Gauderer MW, Ponsky JL, Izant RJ Jr. Gastrostomy without laparotomy: a percutaneous endoscopic technique. J Pediatr Surg. 1980;15(6):872–5. https://doi.org/10.1016/s0022-3468(80)80296-x.
2. Ell C, May A, Pech O, et al. Curative endoscopic resection of early esophageal adenocarcinomas (Barrett's cancer). Gastrointest Endosc. 2007;65(1):3–10. https://doi.org/10.1016/j.gie.2006.04.033.
3. von Renteln D, Schiefke I, Fuchs KH, Raczynski S, Philipper M, Breithaupt W, Caca K, Neuhaus H. Endoscopic full-thickness plication for the treatment of gastroesophageal reflux disease using multiple Plicator implants: 12-month multicenter study results. Surg Endosc. 2009;23(8):1866–75. https://doi.org/10.1007/s00464-009-0490-7.
4. Rattner DW, Hawes R, Schwaitzberg S, Kochman M, Swanstrom L. The Second SAGES/ASGE White Paper on natural orifice transluminal endoscopic surgery: 5 years of progress. Surg Endosc. 2011;25(8):2441–8. https://doi.org/10.1007/s00464-011-1605-5.
5. Fuchs KH, Meining A, von Renteln D, Fernandez-Esparrach G, Breithaupt W, Zornig C, Lacy A. Euro-NOTES Status Paper: from the concept to clinical practice. Surg Endosc. 2013;27(5):1456–67. https://doi.org/10.1007/s00464-013-2870-2.
6. Inoue H, Minami H, Kobayashi Y, et al. Peroral endoscopic myotomy (POEM) for esophageal achalasia. Endoscopy. 2010;42(4):265–71. https://doi.org/10.1055/s-0029-1244080.
7. Pearl J, Pauli E, Dunkin B, Stefanidis D. SAGES endoluminal treatments for GERD. Surg Endosc. 2017;31(10):3783–90. https://doi.org/10.1007/s00464-017-5639-1.
8. Chang KJ. Endoscopic foregut surgery and interventions: the future is now. The state-of-the-art and my personal journey. World J Gastroenterol. 2019;25(1):1–41. https://doi.org/10.3748/wjg.v25.i1.1.
9. Kuellmer A, Mueller J, Caca K, et al. Endoscopic full-thickness resection for early colorectal cancer. Gastrointest Endosc. 2019;89(6):1180–1189.e1. https://doi.org/10.1016/j.gie.2018.12.025.
10. Meier B, Schmidt A, Glaser N, Caca K. Endoscopic full-thickness resection of gastric subepithelial tumors with the gFTRD-system: a prospective pilot study (RESET trial). Surg Endosc. 2020;34(2):853–60. https://doi.org/10.1007/s00464-019-06839-2.
11. Nau P, Paul E, Sandler BJ, Trus T, editors. The SAGES Manual of Flexible Endoscopy. Springer; 2020. https://doi.org/10.1007/978-3-030-23590-1.
12. Kaindlstorfer A, Koch OO, Antoniou SA, Asche KU, Granderath FA, Pointner R. A randomized trial on endoscopic full-thickness gastroplication versus laparoscopic antireflux surgery in GERD patients without hiatal hernias. Surg Laparosc Endosc Percutan Tech. 2013;23(2):212–22. https://doi.org/10.1097/SLE.0b013e3182827f79.
13. Stavropoulos SN, Modayil R, Friedel D. Current applications of endoscopic suturing. World J Gastrointest Endosc. 2015;7(8):777–89. https://doi.org/10.4253/wjge.v7.i8.777.
14. Bardaro SJ, Swanström L. Development of advanced endoscopes for Natural Orifice Transluminal Endoscopic Surgery (NOTES). Minim Invasive Ther Allied Technol. 2006;15(6):378–83. https://doi.org/10.1080/13645700601038069.
15. Thompson CC, Ryou M, Soper NJ, Hungess ES, Rothstein RI, Swanstrom LL. Evaluation of a manually driven, multitasking platform for complex endo-

luminal and natural orifice transluminal endoscopic surgery applications (with video). Gastrointest Endosc. 2009;70(1):121–5. https://doi.org/10.1016/j.gie.2008.11.007.

16. Fuchs KH, Breithaupt W. Transgastric small bowel resection with the new multitasking platform EndoSAMURAI™ for natural orifice transluminal endoscopic surgery. Surg Endosc. 2012;26(8):2281–7. https://doi.org/10.1007/s00464-012-2173-z.
17. Perretta S, Dallemagne B, Barry B, Marescaux J. The ANUBISCOPE® flexible platform ready for prime time: description of the first clinical case. Surg Endosc. 2013;27(7):2630. https://doi.org/10.1007/s00464-013-2818-6.
18. Yeung BP, Gourlay T. A technical review of flexible endoscopic multitasking platforms. Int J Surg. 2012;10(7):345–54. https://doi.org/10.1016/j.ijsu.2012.05.009.
19. Swain P, Park PO. Endoscopic suturing. Best Pract Res Clin Gastroenterol. 2004;18(1):37–47.
20. Schiefke I, Neumann S, Zabel-Langhennig A, Moessner J, Caca K. Use of an endoscopic suturing device (the "ESD") to treat patients with gastroesophageal reflux disease, after unsuccessful EndoCinch endoluminal gastroplication: another failure. Endoscopy. 2005;37(8):700–5.
21. Bergström M, Swain P, Park PO. Early clinical experience with a new flexible endoscopic suturing method for natural orifice transluminal endoscopic surgery and intraluminal endosurgery (with videos). Gastrointest Endosc. 2008;67(3):528–33. https://doi.org/10.1016/j.gie.2007.09.049.
22. Chiu PW, Hu B, Lau JY, Sun LC, Sung JJ, Chung SS. Endoscopic plication of massively bleeding peptic ulcer by using the Eagle Claw VII device: a feasibility study in a porcine model. Gastrointest Endosc. 2006;63(4):681–5.
23. Pescarus R, Shlomovitz E, Sharata AM, Cassera MA, Reavis KM, Dunst CM, Swanström LL. Endoscopic suturing versus endoscopic clip closure of the mucosotomy during a per-oral endoscopic myotomy (POEM): a case-control study. Surg Endosc. 2016;30(5):2132–5. https://doi.org/10.1007/s00464-015-4464-7.
24. Han S, Wani S, Kaltenbach T, Soetikno R, Hammad H. Endoscopic suturing for closure of endoscopic submucosal dissection defects. VideoGIE. 2019;4(7):310–3. https://doi.org/10.1016/j.vgie.2019.04.018. eCollection 2019 Jul.
25. Ligresti D, Barbuscio I, Granata A, Martino A, Amata M, Volpes R, Traina M. Endoscopic closure of gastrocolocutaneous fistula following percutaneous endoscopic gastrostomy, by OverStitch Endoscopic Suturing System. Endoscopy. 2019; https://doi.org/10.1055/a-0956-6792.
26. Wannhoff A, Hofmann C, Meier B, Birk D, Caca K. Endoscopic sleeve gastroplasty for severe obesity by full-thickness suturing using the GERDX device. Endoscopy. 2019;51(2):E34–5. https://doi.org/10.1055/a-0756-7921.
27. Swanstrom LL, Whiteford M, Kajanchee Y. Developing essential tools to enable transgastric surgery. Surg Endosc. 2008;22(3):600–4.
28. Swanstrom LL. Beyond endoluminal therapeutic endoscopy. Gastrointest Endosc. 2007;66(1):121–2. https://doi.org/10.1016/j.gie.2006.12.006.
29. Spaun GO, Zheung B, Swanstrom LL. A multitasking platform for natural orifice transluminal endoscopic surgery (NOTES): a benchtop comparison of a new device for flexible endoscopic surgery and a standard dual-channel endoscope. Surg Endosc. 2009;23:2720–7.
30. Horgan S, Vanuno D. Robots in laparoscopic surgery. J Laparoendosc Adv Surg Tech A. 2001;11(6):415–9.
31. Jacobsen G, Berger R, Horgan S. The role of robotic surgery in morbid obesity. J Laparoendosc Adv Surg Tech A. 2003;13(4):279–83.
32. Talamini MA, Chapman S, Horgan S, Melvin WS, Academic Robotics Group. A prospective analysis of 211 robotic-assisted surgical procedures. Surg Endosc. 2003;17(10):1521–4.
33. Kume K, Sakai N, Goto T. Development of a novel endoscopic manipulation system: the Endoscopic Operation Robot ver.3. Endoscopy. 2015;47(9):815–9. https://doi.org/10.1055/s-0034-1391973.
34. Saito Y, Sumiyama K, Chiu PW. Robot assisted tumor resection devices. Expert Rev Med Devices. 2017;14(8):657–62. https://doi.org/10.1080/17434440.2017.1358087.
35. Phee SJ, Low SC, Huynh VA, Kencana AP, Sun ZL, Yang K. Master and slave transluminal endoscopic robot (MASTER) for natural orifice transluminal endoscopic surgery (NOTES). Conf Proc IEEE Eng Med Biol Soc. 2009:1192–5. https://doi.org/10.1109/IEMBS.2009.5333413.
36. Shi Y, Zhou C, Xie L, Chen Y, Jiang J, Zhang Z, Deng Z. Research of the master-slave robot surgical system with the function of force feedback. Int J Med Robot. 2017;13(4) https://doi.org/10.1002/rcs.1826.
37. Rentschler ME, Hadzialic A, Dumpert J, Platt SR, Farritor S, Oleynikov D. In vivo robots for laparoscopic surgery. Stud Health Technol Inform. 2004;98:316–22.
38. Peters BS, Armijo PR, Krause C, Choudhury SA, Oleynikov D. Review of emerging surgical robotic technology. Surg Endosc. 2018;32(4):1636–55. https://doi.org/10.1007/s00464-018-6079-2.
39. Zorn L, Nageotte F, Zanne P, Legner A, Dallemagne B, Marescaux J, de Mathelin M. Novel telemanipulated robotic assistant for surgical endoscopy: preclinical application to ESD. IEEE Trans Biomed Eng. 2018;65(4):797–808. https://doi.org/10.1109/TBME.2017.2720739.
40. Berthet-Rayne P, Gras G, Leibrandt K, Wisanuvej P, Schmitz A, Seneci CA, Yang GZ. The i$^2$Snake Robotic Platform for Endoscopic Surgery. Ann Biomed Eng. 2018;46(10):1663–75. https://doi.org/10.1007/s10439-018-2066-y.

41. Kume K, Sakai N, Ueda T. Development of a novel gastrointestinal endoscopic robot enabling complete remote control of all operations: endoscopic therapeutic robot system (ETRS). Gastroenterol Res Pract. 2019;6909547 https://doi.org/10.1155/2019/6909547.
42. Hwang M, Kwon DS. K-FLEX: a flexible robotic platform for scar-free endoscopic surgery. Int J Med Robot. 2020; https://doi.org/10.1002/rcs.2078.
43. Broderick RC, Omelanczuk P, Harnsberger CR, Fuchs HF, Berducci M, Nefa J, Nicolia J, Almadani M, Jacobsen GR, Sandler BJ, Horgan S. Laparoscopic cholecystectomy using a novel single-incision surgical platform through a standard 15 mm trocar: initial experience and technical details. Surg Endosc. 2015;29(5):1250–6. https://doi.org/10.1007/s00464-014-3779-0.
44. Berducci M, Fuchs HF, Omelanczuk P, Broderick RC, Harnsberger CR, Langert J, Nefa J, Jaureguiberry P, Gomez P, Miranda L, Jacobsen GR, Sandler BJ, Horgan S. Phase II clinical experience and long-term follow-up using the next-generation single-incision platform FMX314. Surg Endosc. 2016;30(3):953–60. https://doi.org/10.1007/s00464-015-4319-2.
45. Datta RR, Dieplinger G, Wahba R, et al. True single-port cholecystectomy with ICG cholangiography through a single 15-mm trocar using the new surgical platform "symphonX": first human case study with a commercially available device. Surg Endosc. 2020;34(6):2722–9. https://doi.org/10.1007/s00464-019-07229-4.
46. Walter B, Schmidbaur S, Rahman I, Albers D, Schumacher B, Meining A. The BougieCap – a new method for endoscopic treatment of complex benign esophageal stenosis: results from a multicenter study. Endoscopy. 2019;51(9):866–70. https://doi.org/10.1055/a-0959-1535.
47. Brand M, Hofmann N, Ho CN, Meining A. The Over-The-Scope-Grasper (OTSG). Endoscopy. 2020; https://doi.org/10.1055/a-1187-0178.
48. Meining A. Endoneering: a new perspective for basic research in gastrointestinal endoscopy. United European Gastroenterol J. 2020;8(3):241–5. https://doi.org/10.1177/2050640620913433.
49. Fuchs KH, Neki K, Lee AM, Dominguez R, Broderick RC, Sandler BJ, Horgan S. New suturing system for flexible endoscopy in the gastrointestinal tract. Jap J Gastro Hepatol. 2021;V6(2):1–6.