Development of the NOTES Concept
Natural orifice translumenal endoscopic surgery (NOTES) is an endoscopic technique whereby surgical interventions can be performed with a flexible endoscope passed through a natural orifice (mouth, vulva, urethra, anus) then through a translumenal opening of the stomach, vagina, bladder, or colon [1]. NOTES has the potential to provide no scarring, reduced pain, and faster patient recovery compared to open and laparoscopic surgical procedures [1]. We present herein the landmarks in the history of NOTES, from the early stages of endoscopy and laparoscopy to its current development.

Prehistory of NOTES (from ancient times to the late twentieth century)

It is difficult to date when people started to have a look into human bodies, and even harder to credit one individual with the invention of endoscopy. The earliest descriptions of endoscopy are by Hippocrates (460–375 BC), who described a rectal speculum. A three-bladed vaginal speculum was found in the ruins of Pompeii, demonstrating that Roman medicine also involved primitive endoscopic tools. At this time, nothing but ambient light was used, and only rigid instruments were available. Major technological developments leading to modern endoscopy and to modern laparoscopy were born in the nineteenth and twentieth centuries [2].

A brief history of endoscopy [3]
The first issue faced by the pioneers of endoscopy was the illumination problem. The first gastroscopy was reported by Kussmaul in 1868 [4]. Joseph Swan and Thomas Edison invented the incandescent electric light bulb in 1878, but this technology was incorporated into endoscopes only at the beginning of the twentieth century [3]. The second and more challenging problem was flexibility. Articulated lenses and prisms were proposed by Hoffmann in 1911 [5] and improved in 1932 by Wolf and Schindler, who developed a semi-flexible gastroscope [6]. However, the light source consisted of a distal light bulb that provided poor illumination and produced color distortion. In 1930, Lamm showed that bundles of glass fibers could be used as a conduit for a light source, and that this bundle could be bent with no effects on light transmission [7]. “Coherent” bundles, ordered in such a way that the position of a fiber at one end mirrors its position at the other end, provided a real image of internal organs [8]. An external light source transmitted through flexible and coherent fiber bundles could therefore illuminate internal organs.

Flexibility and illumination were combined by Harold Hopkins in 1954: the flexible fiber imaging device he invented was made of a tube of glass with thin lenses of air [9]. In 1958, Larry Curtiss and Basil Hirschowitz improved this system by using a highly transparent optical quality glass to give birth to a flexible fiberoptic endoscope [10].

In the late 1970s, the charge-coupled device (CCD) was incorporated into an endoscope [11]. This development heralded the modern era of endoscopy. The CCD allowed the display of endoscopic images on television screens and the connection of endoscopes and computers. From this major shift started a two-decade period described by Sivak as “the golden era of gastrointestinal endoscopy” [3]. Major achievements, which have since become routine procedures, were reported: endoscopic retrograde pancreatography (1968), colonoscopic polypectomy (1969), endoscopic retrograde cholangiography (1970), endoscopic sphincterotomy with bile duct stone removal (1974), percutaneous endoscopic gastrostomy (1980), endoscopic injection sclerotherapy (1980), endoscopic ultrasonography (1980), electronic CCD endoscope (1983), endoscopic control of upper...
SECTION 1 Development of the NOTES Concept

A brief history of minimally invasive surgery

Georg Kelling (Dresden, Saxony) reported on the first laparoscopic procedure in animals in 1902. Hans Christian Jacobaeus (Sweden) performed the first laparoscopic appendectomy in 1902. Erich Muhe (Erlangen, Germany) in 1986. Muhe met a lot of misunderstanding from his colleagues at this time, and even faced a lawsuit for “improper surgical action” [15]. The use of the computer chip TV camera in 1986 led to the birth of NOTES. It was first described by Hans Seifert (Oldenburg, Germany) in 2000 [27]. After endoscopic transmural drainage of peripancreatic fluid collections is performed with EUS-FNA and wire-guided stent placement, the same transgastric access is expanded with balloon dilatation. The endoscope is advanced through the gastrointestinal wall into the retroperitoneum. Endoscopic removal of infected pancreatic necroses can be achieved under direct visual control.

On the verge of NOTES (1980–2000)

Translumenal endoscopic approaches

From the 1980s to the 2000s, numerous translumenal endoscopic procedures emerged. Some of them are now part of the routine practice of gastrointestinal endoscopy. Various endoscopic techniques consist of the creation of an artificial external opening into the digestive tract for nutritional support or gastrointestinal decompression. Percutaneous endoscopic gastrostomy (PEG) creation without laparoscopic assistance was first reported in 1980 by Gauderer et al. [21], then followed by variations such as percutaneous endoscopic jejunostomy and colostomy [22,23]. Endoscopic ultrasound (EUS) arose in 1980 [24]. Diagnostic EUS procedures were first based on imaging and Doppler only. Under EUS guidance, the fine needle aspiration (FNA) technique was developed to allow the sampling of lesions through the digestive wall [25]. EUS-FNA is now commonly used to target lesions in the mediastinum, in the biliary and pancreatic area, and in the mesorectum. Further refinement of the EUS technique has led to the ability to pass instruments (guidewires, fiducials, coils, radioactive seeds, pharmacological agents) using fine needles, leading to the concept of interventional EUS. Biliary, pancreatic, and vascular therapeutic EUS techniques are currently under evaluation [26].

Translumenal per-oral endoscopic access to the retroperitoneum is another gastrointestinal technique preceding the birth of NOTES. It was first described by Hans Seifert (Oldenburg, Germany) in 2000 [27]. After endoscopic transmural drainage of peripancreatic fluid collections is performed with EUS-FNA and wire-guided stent placement, the same transgastric access is expanded with balloon dilatation. The endoscope is advanced through the gastrointestinal wall into the retroperitoneum. Endoscopic removal of infected pancreatic necroses can be achieved under direct visual control.
CHAPTER 1 History of NOTES

Flexible endoscopic procedures have become more and more invasive over recent decades. At the end of the twentieth century, frontiers in endoscopy were broken in a step-wise fashion. Diagnosis endoscopy is now possible all along the digestive tract (including the small bowel) and even in the duct of its main accessory glands (cholangioscopy, pancreatoscopy) [32]. Imaging and sampling of organs beyond the digestive tract have been made possible by EUS-FNA. The most recent step was the possibility of voluntarily causing a breach in the integrity of the digestive wall to access and treat necrosis in the retroperitoneum [33].

Conversely, surgery is getting less and less invasive. Dr. Hunter’s quote in 1762 — “Surgery, gaining much from the general advance of knowledge, will be rendered both knifeless and bloodless” — was much ahead of his time. At the end of the twentieth century, laparoscopy has been demonstrated safe and cost-efficient, in a wide range of applications in abdominal, pelvic, and thoracic surgery. It has been fully accepted by medical and surgical communities. Minimally invasive surgery has therefore gained patients’ satisfaction over the years and is now a standard of care for many indications. Some of its latest developments are the possibility to access and to treat through natural orifices (mostly through the vagina) and/or through a unique and small parietal incision (as proposed in single-incision laparoscopic surgery, SILS).

NOTES is born from the confluence of these two trends (Figure 1.1). Anthony Kalloo and the team (Figure 1.2) from the Johns Hopkins Hospital (Baltimore, USA) reported on the first NOTES procedure (transgastric peritoneoscopy) in a survival porcine model during the 2000 edition of the Digestive Disease Week (DDW) (see Video 1.1). In this initial approach (finally published in 2004) [34], access to the peritoneal cavity was gained with a flexible endoscope through the mouth and after needle-knife puncture.

Transvaginal laparoscopy

Transvaginal hydrolaparoscopy is a surgical technique that arose in the 1990s with the main purpose of diagnosing and treating infertility in women. The technique used a modified rigid and reusable laparoscope. The so-called “fertiloscopy” procedure combines a hydrolaparoscopy advanced through the vagina and the pouch of Douglas together with hysteroscopy and salpingoscopy with dye. A pioneer in this field is Antoine Watrelot (Lyon, France). After he developed the technique, he demonstrated that fertiloscopy is useful in the diagnosis of tubo-peritoneal abnormalities (a major causes of infertility), enables rational choices in the therapeutic strategy of infertility, improves pregnancy rates, and allows reductions in costs [31]. The technique does not involve a flexible instrument and is not dedicated to the exploration of the entire peritoneal cavity. However, it is seen as a close step on the way to NOTES.

The birth of NOTES (2000)

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and balloon dilatation of the anterior wall of the stomach. Peritoneoscopy and liver biopsies were performed. Hemoclips were used to close the gastrotomy. Two years later, Rao and Reddy (Hyderabad, India) reported on the first human case (transgastric NOTES appendectomy) in a DDW video session (Figure 1.3) [35].


After its initial description, a few research groups showed interest in NOTES. At this early stage, much work was done out of the public view. Developmental studies aimed to make flexible endoscopes and ancillary instruments suitable and safe for transluminal access, and surgical procedures were being developed. Endoscope and overtube prototypes were conceived and designed with larger accessory channels, increased push force, wider freedom of movement, and variable rigidity [36]. Approximating and sewing instruments were developed. Among others, the group of Paul Swain (London, United Kingdom) was extremely active on this topic [37]. Along with these advances in the design of instruments, early procedures were refined, with animal experiments on organ removal and anastomosis, leading to the first descriptions of NOTES gastrojejunostomy, fallopian tube ligation, hysterectomy, and cholecystectomy [38–41].

NOTES booming (2005–2008)

NOTES societies

In July 2005, US leaders in the fields of both laparoscopy and gastrointestinal endoscopy came together for a summit meeting in New York City. These experts built up the Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR) group, a joint initiative supported by the American Society for Gastrointestinal Endoscopy (ASGE) and the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) (Figure 1.4). From this meeting, the NOSCAR group published a first White Paper in 2006 that aimed to guide research on NOTES [42]. The key message of the group was that developmental work and animal study were required before safe clinical evaluation could be attempted (Table 1.1). The group successfully called for the involvement of the industries of both endoscopy and surgery. Their first annual meeting under the name of NOSCAR was held in Boston in 2006. The first NOSCAR research grants were awarded in 2006, since then followed by yearly awards. Other international groups with similar goals and means followed this move throughout the world. In 2007, the first joint meeting of the European Association for Endoscopic Surgery (EAES) and the European Society of Gastrointestin-
CHAPTER 1 History of NOTES

A few clinical reports on transgastric NOTES have been published. In most cases, laparoscopic assistance was deemed necessary by the operators and by ethics committees. Laparoscopy-assisted transgastric diagnostic flexible peritoneoscopy has been performed at the time of oncological or bariatric surgery in short series. Only a few cases of pure transgastric NOTES procedures have been reported in human patients.

Transvaginal NOTES breakthrough

Based on the strong experience of fertiloscopy preceding the birth of NOTES, the transvaginal route met most of the expectations of surgeons for a safe and reliable access to the peritoneal cavity. Although it excludes male patients to benefit from the technique, most surgeons involved in the development of NOTES proposed to move forward by starting clinical series with the transvaginal approach. Cholecystectomy was felt to be a standard surgical procedure that could be easily translated from the laparoscopic to the NOTES approach. The first series were lap-assisted (hybrid NOTES). Audacious surgeons from South America took the lead. In 2007, Ricardo Zorron (Rio de Janeiro, Brazil) published the first report of transvaginal hybrid NOTES cholecystectomy (Figure 1.5). As the technique was refined, rigid laparoscopic instruments and ports were progressively reduced in terms of numbers and size. Jacques Marescaux (Figure 1.6) from Strasbourg, France, soon followed by Mark Bessler (Figure 1.7) from New York, USA, reported on the first NOTES cholecystectomy without any laparoscopic assistance (also known as “pure NOTES”). These major achievements received a large echo in the media, favoring further development and evaluation of the technique. The first series of transvaginal hybrid NOTES cholecystectomy were published in 2008 [64–66]. Data from the German NOTES registry have since confirmed that transvaginal

Table 1.1 Potential barriers to the development of NOTES, as listed by the NOSCAR consortium.

<table>
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<tr>
<th>Potential Barriers</th>
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<tr>
<td>Access to peritoneal cavity</td>
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<tr>
<td>Gastric (intestinal) closure</td>
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<tr>
<td>Prevention of infection</td>
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<tr>
<td>Development of suturing and anastomotic devices</td>
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<td>Spatial orientation</td>
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<td>Development of a multitasking platform to accomplish procedures</td>
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<td>Management of intraperitoneal complications</td>
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<td>Physiologic untoward events</td>
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<td>Compression syndromes</td>
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<td>Training</td>
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(Reproduced from Rattner and Kalloo [42], with kind permission from Springer Science + Business Media.)

NOTES early animal experiments

From the initial reports of per-oral transgastric flexible peritoneoscopy, it was expected for NOTES to offer a wide array of diagnostic and therapeutic procedures. Under the guidance of NOTES societies, and with their funding in many cases, numerous procedures and tools were developed in this period in laboratories. Most procedures were attempted in pigs of various breeds, and more rarely in dogs or in human cadavers. The following selection of procedures is not exhaustive, but it gives an idea of the flourishing research activity that emerged from the initial description of NOTES. Early transgastric experimental procedures included creation of anastomosis [41,43,44], gynecologic surgery [39,41,45,46], and cholecystectomy [47]. Transgastric NOTES was combined with other innovative techniques such as EUS [48], confocal endomicroscopy [49], closure devices [47,50–52], and robots [53]. Other access routes to the peritoneal cavity were evaluated, as illustrated by reports on transcolonic peritoneoscopy [54], hernia repair [55], and cholecystectomy [56], on transvesical peritoneoscopy [57] and thoracoscopy [58], and on transesophageal procedures [59].

NOTES in human medicine (2009–2011)

Transgastric NOTES waning

Although most of the above-mentioned transgastric experiments in animals met with technical success, most procedures were tedious and did not allow immediate translation for clinical practice. Since the initial report of transgastric NOTES appendectomy by Rao and Reddy in 2002 [35], only a few clinical reports on transgastric NOTES have been published. In most cases, laparoscopic assistance was deemed necessary by the operators and by ethics committees. Laparoscopy-assisted transgastric diagnostic flexible peritoneoscopy has been performed at the time of oncological [60] or bariatric [61] surgery in short series. Only a few cases of pure transgastric NOTES procedures have been reported in human patients [62].
hybrid NOTES cholecystectomy was a safe alternative to the laparoscopic approach. Although not compared to laparoscopy, NOTES was favorably evaluated in 551 patients (including 470 cholecystectomies), with a complication rate of 3.1% and a conversion rate to laparoscopy or to open surgery in 4.9% [67]. The NOSCAR consortium has started a prospective multicenter trial comparing NOTES cholecystectomy with conventional laparoscopic cholecystectomy in the USA.

NOTES offspring

The development of NOTES has served (and is still serving) other concepts in the development of interventional endoscopy and minimally invasive surgery.

Collateral development in interventional endoscopy

The development of innovative devices for access and closure during NOTES procedures has offered new possibilities to therapeutic endoscopists. Submucosal endoscopy is a direct result of targeting NOTES procedures in an attempt to develop safe access and quick closure. An early proposal to secure access to the mediastinum and to the peritoneal cavity was to create endoscopically a tunnel in the submucosal layer of the digestive wall. The technique was named submucosal endoscopy with mucosal flap (SEMF). By separating the mucosal access to the submucosa from the muscular breach giving access to surrounding organs, and by using a mucosal flap to cover the tunnel, the operators aimed to decrease the risk of contamination [59,68–70]. Since then, this approach has been developed and evaluated for the endoscopic treatment of achalasia, called per-oral endoscopic myotomy (POEM) [71,72]. The research on NOTES has also provided new tools for endoscopic full-thickness resection of tumors [73,74] and for the treatment of endoscopic perforations. Bariatric endoscopy also greatly benefits from the research on endoscopic sutures and anastomosis during NOTES [75,76].

Collateral development in minimally invasive surgery

Transumbilical surgery is another example. The umbilicus is not strictly considered as a natural orifice and it is therefore not included in the narrow spectrum of NOTES. However, transumbilical surgery clearly benefits from the advances of NOTES (and vice versa). The concepts of natural orifice transumbilical surgery (NOTUS), transumbilical endoscopic surgery (TUES), and transumbilical laparoscopic assisted (TULA) have arisen from this idea. They are now endlessly combined to other concepts, including laparo-endoscopic single-site (LESS) and single-incision laparoscopic surgery (SILS), and flexible endoscopy (flexible SILS), thus expo-
nentially increasing the field of minimally invasive surgery. Transanal endoscopic microsurgery (TEM) is also an expanding field of surgery with a close relationship to the technical advances of NOTES [77].

Conclusion
Initially described by gastroenterologists by a pure per-oral transgastric route in the pig model, NOTES is now mainly performed by surgeons, through the transvaginal route, in human patients. NOTES is a result of the natural evolution of endoscopy and laparoscopic surgery in the quest to deliver less invasive patient care. It is currently in its infancy but will grow to be part of our armamentarium of approaches to patient care.

Chapter video clip

Video 1.1 First NOTES peritoneoscopy.

References

Development of the NOTES Concept

CHAPTER 1 History of NOTES


