Review

ClinicalPractice

Achieving scarless renal surgery: is it feasible?

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Practice Points

- Laparoendoscopic single-site surgery (LESS) and particularly natural orifice transluminal endoscopic surgery (NOTES) are techniques that are still in evolution, and room exists for improvements in these technologies. More studies are needed in order to evaluate their outcomes and potential benefits.
- NOTES/LESS require increased operating times compared with standard laparoscopic procedures.
- Cost–benefit analyses are needed in order to demonstrate whether NOTES/LESS will eventually be used more widely.
- These novel techniques potentially benefit only a small group of patients and requires stringent patient selection. Hence, they are mainly available in high-volume centers where sufficient patients can be recruited to make the procedure economically viable.
- There are still some concerns relating to the safety of transluminal access. Additional complications relating to incomplete closure of access sites, especially in transcolonic NOTES, has been implicated with an increased risk of surgical site infection.
- Currently, there is inadequate clinical evidence on the benefits of NOTES, particularly with regards to improve cosmesis, early ambulation, reduced morbidity and oncological outcomes. The evidence presently available is level 4, and more comparative studies of LESS versus standard laparoscopic and/or robotic procedures in the various potentially viable procedures (e.g., simple and radical nephrectomy) are required.
- It still remains to be seen whether NOTES/LESS have any other benefits apart from cosmesis. Whether patients truly benefit from 'scarless' surgery still remains to be fully established, and this has to be fully explicated to them when decisions on surgical interventions are being made. Studies should also be designed carefully in order to incorporate quality of life scores.
- Robotic surgery is becoming increasingly popular in urology and has already replaced laparoscopy in some parts of the world. Its role in LESS and NOTES, however, needs to be investigated further.

Renewed interest in 'scarless' surgery has been generated by the advent of natural orifice transluminal endoscopic surgery and laparoendoscopic single-site surgery (LESS). Both techniques aim at minimizing surgical scarring and morbidity, thereby improving recovery. We appraise the literature and examine the future perspectives of these techniques in renal surgery. Successful applications in renal extirpative surgery with natural orifice transluminal endoscopic surgery have been reported, but it still remains a technique in evolution. LESS is gradually being embraced and contemporary procedures such as nephrectomy and pyeloplasty are increasingly being performed. Evidence endorsing the benefits of LESS still remains limited. Innovations in technology, instrumentation and the incorporation of robotic systems has opened up fascinating avenues and the dream of truly 'scarless' surgery seems achievable.

Future Medicine part of fsg

Keywords: • laparoendoscopic single-site surgery • laparoscopy • LESS • minimally invasive surgery • natural orifice transluminal endoscopic surgery • nephrectomy • NOTES • pyeloplasty

The benefits of using minimally invasive surgery (MIS) techniques in urology have been well established, promising low postoperative complication rates, early recovery and improved cosmesis. Over the past 10 years, these have evolved significantly with the advent of novel techniques such as laparoendoscopic single-site surgery (LESS) and natural orifice transluminal endoscopic surgery (NOTES). These techniques have been employed in various other surgical disciplines and a range of procedures, such as cholecystectomy and hysterectomy, have been successfully performed. The main scope of such techniques is to potentially achieve 'scarless' surgery by making incisions in 'hidden' areas, such as the umbilicus or alternatively using the natural orifices.

The concept of NOTES is based on the use of a hollow organ to gain access into the peritoneal cavity, thereby avoiding the need for making large skin incisions. Different surgical routes that have been explored to access the peritoneal cavity include the vagina, stomach, colon and the urinary bladder. NOTES can be broadly subdivided into pure NOTES, in which no transabdominal access is involved, or hybrid NOTES, which employs the use of accessory ports. Kalloo *et al.* were the first to introduce NOTES by performing a transgastric peritoneoscopy at the Johns Hopkins Hospital in Baltimore (MD, USA) [1]. This was followed by Reddy *et al.*, who performed the first transgastric appendectomy in 2004 [2]. Breda *et al.* are credited with introducing the concept of NOTES to urologists by using the vagina for extracting the specimen following a laparoscopic nephrectomy [3]. The first experimental NOTES was reported by Gettman *et al.*, who carried out a transvaginal nephrectomy on a porcine model [4].

LESS mainly uses a solitary abdominal incision for the introduction of a multichannel instrument port, with or without the use of an adjunctive small needlescopic instrument. Hirano *et al.* reported one of the early series of retroperitoneal LESS for adrenalectomy, demonstrating its effectiveness while stressing the technical difficulties of the narrow working space and restriction in manipulation of instruments [5]. The first LESS nephrectomy was performed by Raman *et al.* on pigs, via a single 'keyhole' umbilical incision [6]. In the field of urology, advances in LESS have led to employing the approach to perform nephrectomy, partial nephrectomy, nephroureterectomy, pyeloplasty and prostatectomy.

The aims of this article are to provide an overview of the history and recent advancements in LESS and NOTES, particularly in renal surgery, with a focus on the current and future challenges faced and to evaluate the further direction of these techniques.

Methods

References were retrieved following a thorough bibliographic search using OVID Medline, EMBASE, the Cochrane Database and urological conference proceedings. Keywords used included 'natural orifice transluminal endoscopic surgery'; 'NOTES'; 'robotic assisted NOTES'; 'hybrid NOTES'; 'LESS'; 'laparoendoscopic single-site'; 'single port laparoscopy'; 'scarless surgery'; 'nephrectomy'; 'nephrouretectomy'; and 'renal cryotherapy'. These terms were arranged by variable combinations of the Boolean operators 'AND' and 'OR'. A limitation was placed to include only English-language articles/abstracts and those with translations. We included all human, cadaveric and animal studies. Relevant review articles, case reports and books were considered. Primary articles referenced in review articles and books were also reviewed. We also reviewed papers on patient and public perspectives on NOTES/LESS in order to provide a holistic opinion on these novel techniques.

Laparoendoscopic single-site surgery

LESS techniques & challenges

LESS is also known as single-incision laparoscopic surgery, single-port access, single-site laparoscopy, one-port umbilical surgery, single laparoscopic port procedure, single-port laparoscopy, single laparoscopic incision transabdominal surgery and single instrument port laparoscopic surgery. The nomenclatures describe the laparoscopic techniques that consolidate all ports within a single skin incision. It was developed in an attempt to improve cosmetic appearance compared with standard laparoscopy. LESS requires a multichannel working port, usually placed in the umbilicus or below [7]. Alternatively, separate single ports can be introduced through the same skin incision by separate fascial stabs. The patient is placed in a modified or 'full-flank' position as in standard transperitoneal or retroperitoneal renal surgery. Upon the establishment of pneumoperitoneum and the introduction of the multichannel port, conventional laparoscopic or flexible instruments can be introduced.

The technique was first described in 1969 when "single trocar operative laparoscopy" was performed using a 12-mm laparoscope with one operative channel [8]. LESS failed to gain popularity until recently, largely due to the various technical challenges involved with the procedure. Compared with conventional

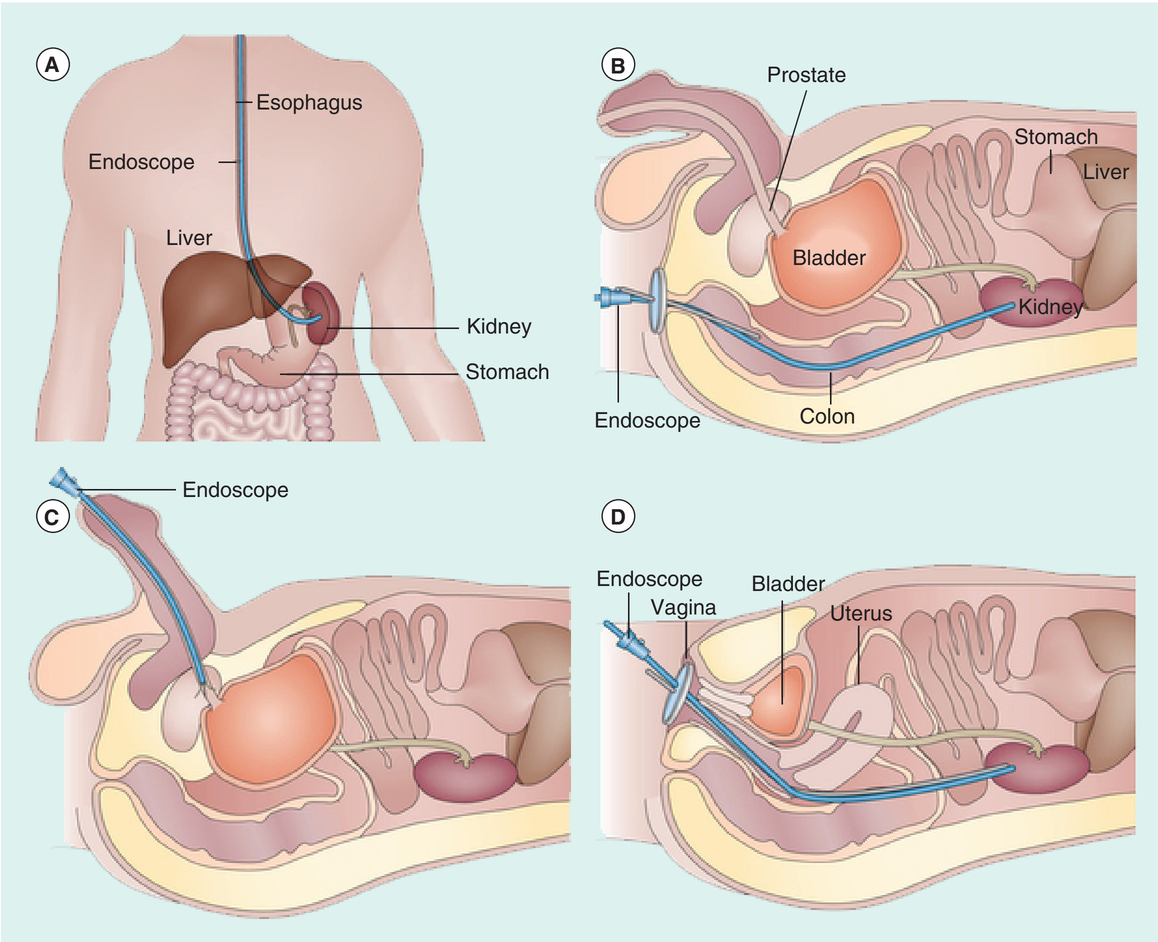

Figure 1. Approaches for natural orifice transluminal endoscopic surgery nephrectomy. **(A)** Transgastric, **(B)** transrectal, **(C)** transurethral; and **(D)** transvaginal approaches.
Reproduced with permission from [58].

laparoscopy, the main difficulties are loss of triangulation and depth perception (due to the parallel positioning of the camera and working instruments), reduced range of instrument movements, limited extra-abdominal working space for the surgeon(s) and an occasionally compromised field of view due to adjacent working instruments [9]. Surgeons with expertise in standard laparoscopic techniques can adopt LESS safely. A recent study on the learning curve for LESS showed that there was a significant improvement in the operative time after ten cases, with further modest improvements after 20 cases [10]. The laparoscopic equipment industry has played a crucial role in the development of LESS by introducing purpose-built multichannel ports, roticulating instruments, high-definition cameras and multilength working instruments.

Some of the LESS techniques adopted in urology include pyeloplasty, extirpative renal surgery, adrenalectomy, radical prostatectomy and pelvic reconstructive procedures. In this article, we will focus on LESS procedures involving the kidney.

LESS pyeloplasty

Pyeloplasty has been a desirable target for LESS largely due to the absence of specimen retrieval, hence avoiding the need for an extraction incision. In addition, pelviureteric junction obstruction (which forms the main indication for pyeloplasty) is usually discovered at a younger age and, in this subgroup of patients who are increasingly conscious of their body image, the presence of scarring does matter. This particular cohort has a favorable view of LESS due to its perceived association with 'scarless' surgery and presumed lower morbidity. However, several technical challenges exist with LESS pyeloplasty that relate to the complexities involved in tissue retraction, mobilization and the intricacies involved in the suturing of the anastomosis [11].

A randomized controlled trial comparing LESS with conventional laparoscopic pyeloplasty revealed a longer operative time (195 vs 146 minutes; $p = 0.001$) but a shorter time to return to normal activity (8.65 vs 11.53 days; $p = 0.01$) [12]. In the largest published series of

Table 1. Clinical studies on natural orifice transluminal endoscopic surgery nephrectomy.

Author (year)	No. of patients (age, years)	Natural orifice	Additional ports	Type of surgery	Indication	Mean operative time (min)	Length of stay (h)	Mean blood loss (ml)	Complications	Ref.
Breda *et al.* (1993)	1 (51)	Transvaginal (extraction)	Abdominal (laparoscopic nephrectomy)	Laparoscopic nephrectomy	Nonfunctioning kidney	–	–	–	–	[3]
Gill *et al.* (2002)	10 (67)	Transvaginal (extraction)	Four-port laparoscopic nephrectomy	Radical nephrectomy	Tumour	195 total (35 extraction)	24	100	Spotting	[32]
Branco *et al.* (2008)	1 (22)	Transvaginal	Abdominal: 5 mm ×2	Simple nephrectomy	Abnormal functioning kidney		12		None	[33]
Castillo *et al.* (2009)	2	Transvaginal	Abdominal: 3 mm, 10 mm	Simple nephrectomy	Renal atrophy, recurrent UTI	80	36	200	None	[34]
Kaouk *et al.* (2009)	1 (57)	Transvaginal	Umbilicus: 5 mm	Simple nephrectomy	Atrophic kidney, previous TAHBSO	307	23	100	None	[35]
Allaf *et al.* (2010)	1 (48)	Transvaginal (extraction)	Abdominal: 5 mm, 12 mm ×2	Donor nephrectomy	Live donor	185	21	100	–	[36]
Sotelo *et al.* (2010)	1	Transvaginal	Umbilicus: R-PORT®	Radical nephrectomy	Renal tumor (pT1b)	222	24	150	Readmission for intra-abdominal collection, percutaneous drainage	[37]
Porpiglia *et al.* (2011)	1 (58)	Transvaginal	Umbilicus: 3.5 mm; flank: 3.5 mm ×2	Radical nephrectomy (2); simple nephrectomy (3)	Renal tumor (pT1b); renal atrophy	120	62.4	160	None	[38]
Kaouk *et al.* (2010)	1 (58)	Transvaginal (TriPort™ and GelPort™)	None	Simple nephrectomy	Atrophic kidney	420	19	50	None	[26]
Alcaraz *et al.* (2010)	14	Transvaginal	Abdominal: 5 mm, 10 mm	Nephrectomy	Renal tumor, lithiasis, renal atrophy	132.9	96	111.2	1× colonic injury	[28]
Alcaraz *et al.* (2011)	20	Transvaginal	Abdominal: 10 mm, 10 mm, 5 mm	Laparoscopic donor nephrectomy	Life donor	116.47 (WIT: 4.98)	98.4	215	1× uterine artery injury. Acute hemorrhage requiring surgery	[39]

NOTES: Natural orifice transluminal endoscopic surgery; TAHBSO: Total abdominal hysterectomy and bilateral salpingo-opherectomy; UTI: Urinary tract infection; WIT: Warm ischemic time.

Table 1. Clinical studies on natural orifice transluminal endoscopic surgery nephrectomy (cont.).

Author (year)	No. of patients (age, years)	Natural orifice	Additional ports	Type of surgery	Indication	Mean operative time (min)	Length of stay (h)	Mean blood loss (ml)	Complications	Ref.
Sotelo *et al.* (2011)	1	Transvaginal	Umbilicus TriPort	Upper pole heminephrectomy	Duplicated renal collecting system	150	?10	50	Developed a urinoma and required a repeat surgical procedure which involved laparoscopic exploration	[27]
Kaouk *et al.* (2012)	1 (61)	Transvaginal	Robotic NOTES	Donor nephrectomy	Life donor	240	48	75	None	[29]

NOTES: Natural orifice transluminal endoscopic surgery; TAHBSO: Total abdominal hysterectomy and bilateral salpingo-opherectomy; UTI: Urinary tract infection; WIT: Warm ischemic time.

LESS pyeloplasty (140 adult patients), complication and resolution of pelviureteric junction obstruction rates were comparable to conventional laparoscopic pyeloplasty [13].

The challenges facing LESS, particularly in relation to difficulties with the triangulation of instruments, have led to the development of robotic LESS (R-LESS) pyeloplasty. Robotic systems, with their advanced ergonomics, better-articulated instruments and improved 3D vision, provide a suitable alternative to conventional LESS. Evidence supporting the benefits of robotic systems incorporating LESS is scarce, but the current trend seems to favor using these systems [14–16].

LESS nephrectomy

The potential advantages and rationale for using LESS in renal extirpative surgery pertain to the usage of fewer ports, thus reducing morbidity by decreasing the incidence of port site hernia, postoperative pain and length of hospital stay. The initial reports involving LESS nephrectomy were published by Rane and Rao in 2008 and later by Raman *et al.* [17,18]. The typical approach described is via a multichannel port inserted through the umbilicus or the suprapubic crease. As described above, the key technical challenges associated with LESS nephrectomy include decreased maneuverability and internal and external clashing of conventional laparoscopic instruments secondary to their close parallel proximity. The introduction of modified instruments will eventually address this limitation by providing an enhanced working space and improved triangulation in the working operative field, thereby enabling the surgeon to have a better range of movement.

There has been a surge of published case series on LESS nephrectomy in the literature over the last 2–3 years, which has demonstrated a promising future for this technique. In one of the first retrospective case–control studies, Raman *et al.* compared the outcomes of 11 LESS nephrectomies with 22 conventional laparoscopic nephrectomies and found similarities in operative times, complication rates and lengths of hospital stay between the groups, but significantly lower estimated blood loss in the LESS group (20 vs 100 ml; $p = 0.001$) [18]. A recent meta-analysis of 1094 cases comparing LESS nephrectomy with conventional laparoscopic nephrectomy found the former to be associated with a longer postoperative time (mean difference: 9.9 min; $p = 0.003$) and a significantly higher rate of conversion to open (6 vs 0.3%; $p = 0.001$) [19]. However, patients who had a LESS nephrectomy experienced less postoperative pain, shorter hospital stay, reduced recovery times and improved cosmetic outcomes.

Table 2. Experimental cases on natural orifice transluminal endoscopic surgery nephrectomy.

Author (year)	Animal (n)	Natural orifice	Other ports	Procedure	Mean operative time (min)	Blood loss (ml)	Specimen retrieval route	Complications	Ref.
Gettman *et al.* (2002)	Porcine (6)	Transvaginal	Abdominal (5); none (1)	Laparoscopic nephrectomy	210 min (5 porcines using abdominal ports); 360 mins (pure transvaginal route)	<30	Vaginal	Bleeding: 1× vascular injury during placement of endoscopic stapler	[4]
Haber *et al.* (2008)	Porcine (10)	Transvaginal	Umbilical	Robotic pyeloplasty, partial nephrectomy, radical nephrectomy	154	72	Vaginal	None	[40]
Haber *et al.* (2009)	Porcine (5)	Transvaginal	None	Nephrectomy (pure NOTES)	113	<50	Vaginal	None	[41]
Clayman *et al.* (2007)	Porcine (1)	Transvaginal	Subumbilical: 12 mm	Simple nephrectomy	300	<50	Vaginal	–	[42]
Lima *et al.* (2007)	Porcine (6)	Transvesical, transgastric	Umbilicus: 5.5 mm	Simple nephrectomy	120	–	Not removed	–	[31]
Ponskey *et al.* (2009)	Porcine (1)	Transgastric, transvaginal	–	Bilateral simple nephrectomy	60	Minimal	Vaginal – intact specimen	None	[43]
Box *et al.* (2008)	Porcine (1)	Transvaginal, transcolonic	Abdominal: da Vinci robot	Nephrectomy	150	<50	Vaginal	None	[44]
Aminsharifi *et al.* (2009)	Canine (10)	Transvaginal	Umbilical	Nephrectomy	101	Minimal	Vaginal	None	[45]
Nadu *et al.* (2009)	Porcine (6)	Transurethral	Umbilical	Nephrectomy	85	<50	Not removed	Periurethral hematoma secondary to dilation of ureter	[46]
Metzelder *et al.* (2009)	Piglets (12)	Transurethral	Umbilical	Nephrectomy tubovariectomy	–	Minimal	Umbilical	–	[47]
Perretta *et al.* (2009)	Porcine (10); cadaver (2)	Transvaginal	None	Retroperitoneal nephrectomy	50	10	Not removed	–	[48]
Aron *et al.* (2009)	Cadaver (4)	Transvaginal QuadPort™	Umbilical: R-PORT®	Nephrectomy	170	None	Vaginal	Abandoned in one cadaver secondary to dense pelvic adhesions	[49]

NOTES: Natural orifice transluminal endoscopic surgery.

Table 2. Experimental cases on natural orifice transluminal endoscopic surgery nephrectomy (cont.).

Author (year)	Animal (n)	Natural orifice	Other ports	Procedure	Mean operative time (min)	Blood loss (ml)	Specimen retrieval route	Complications	Ref.
Bazzi *et al.* (2011)	Porcine (3)	Transrectal: 15 mm	Umbilical: 12 mm	Simple nephrectomy	180	50	Rectal – intact specimen	None	[50]
Baldwin *et al.* (2011)	Porcine (3)	Transurethral: 12 mm	Umbilical: 3 mm, 2 mm	Simple nephrectomy	220	20	Morcellated transurethral	None	[51]
Bazzi *et al.* (2013)	Porcine (5)	Transrectal	Umbilical: 12 mm, gastroscope	Partial nephrectomy	196	59	Rectal	–	[52]
Bazzi *et al.* (2013)	Porcine (5)	Transvaginal	Umbilical: 12 mm, gastroscope	Partial nephrectomy	183	54	Vaginal	–	[52]
Laydner *et al.* (2013)	Cadaver (3)	Transvaginal	Vaginal: R-PORT	Retroperitoneal nephrectomy	238	Nil	Vaginal	Rectal injury in one cadaver, procedure abandoned	[53]
Eyraud *et al.* (2013)	Cadaver (1)	Transrectal	Umbilical: 8 mm, 12 mm; rectal: R-PORT, 8 mm	Nephrectomy and adrenalectomy	145	Nil	Rectal	–	[30]

NOTES: Natural orifice transluminal endoscopic surgery.

There were no significant differences in perioperative complications, estimated blood loss and warm ischemia times between the two techniques. LESS has also been used for live donor nephrectomy. A randomized controlled trial showed no difference in blood loss, length of stay, warm ischemia time or allograft rejection when compared with the conventional multiport laparoscopic technique [20].

A multi-institutional study of 190 cases analyzing the oncological outcomes of patients following LESS partial nephrectomy found overall survival rates of 99, 97 and 88% at 12, 24 and 36 months of follow-up, respectively, and disease-free survival rates of 98, 97 and 97% at 12, 24 and 36 months, respectively [21]. In the same series, the Preoperative Aspects and Dimensions Used for an Anatomical (PADUA) classification of renal tumors score was found to be an independent predictor of a favorable surgical outcome; therefore, patients with low PADUA scores were likely to represent the best candidates for LESS partial nephrectomy. Robot-assisted procedures were associated with a lower overall risk of complications [22].

The 'trifecta' in partial nephrectomy was recently introduced, which is a set of three key outcomes that should form a routine goal during this procedure: negative cancer margin, minimal renal functional decrease and no urological complications [23]. Komninos *et al.* found that the trifecta was achieved in significantly more patients who underwent multiport radical partial nephrectomy compared with those who underwent R-LESS partial nephrectomy [24].

LESS nephroureterectomy has demonstrated equivalent perioperative outcomes when compared with conventional laparoscopic procedures. A recent multicenter series of 101 LESS nephroureterectomies (26% of which were robot assisted) reported an overall postoperative complication rate of 10%, open conversion rate of 3% and estimated blood loss of 230 ml [25]. However, an additional trocar was necessary in 28.7% cases.

LESS extirpative surgery can be effective in experienced hands. However, surgeons and patients have to recognize the significant likelihood of requiring an additional port in order to progress and complete the procedure in a safe manner. With the increasing popularity of robotic equipment and the favorable results associated with this technique, R-LESS renal surgery is likely to lead the way in future developments.

Natural orifice transluminal endoscopic surgery

Experimental & clinical applications

NOTES is currently largely limited to animal/experimental studies; however, there have been published reports of its successful use in renal surgery, such as in simple nephrectomy, radical nephrectomy and partial nephrectomy. NOTES can be performed using only natural orifices with no additional ports (pure NOTES) or with the use of accessory transabdominal ports (hybrid NOTES). The majority of experimental studies have been carried out in porcine models, which have explored a variety of natural orifice access options. NOTES on humans was first carried out by Breda *et al.* in 1993, when an atrophic kidney was extracted via the vagina [3].

One of the most significant milestones in the history of NOTES was when Kaouk *et al.* in 2010 performed the first human pure NOTES transvaginal nephrectomy [26]. A 5-mm needlescopic port was inserted transumbilically in order to inflate the abdomen and a scope was passed in order to aid visualization of the placement of the vaginal port. The total operative time in extracting the atrophic kidney was 420 min and the patient's length of hospital stay was only 19 h, with a minimal blood loss of only 50 ml.

More recently, in 2011, Sotelo *et al.* used an umbilical triport to perform a transvaginal upper pole heminephrectomy in a patient with a duplicated renal collecting system [27]. The mean surgical time was 150 min and the estimated blood loss was 50 ml. Alcarez *et al.* also performed a transvaginal laparoscopic-assisted donor nephrectomy in a 20-year-old woman. The operating time was 116 min, the duration of stay 98 h and blood loss was 215 ml. The patient unfortunately sustained colonic injury and had to be taken back to theater [28].

Robotic-assisted NOTES was first performed by Kaouk *et al.* in 2012 [29]. A 61-year-old woman underwent a robotic-assisted transvaginal donor nephrectomy. The total operating time was 240 min, the length of stay 48h and the estimated blood loss 75 ml. There were no reported operative or postoperative complications.

Various other routes of access investigated involve the transgastric, transrectal and transcolonic approaches (Figure 1). Most recently, in 2013, Eyraud *et al.* performed a transrectal nephrectomy and adrenalectomy on a cadaver, with the aid of an umbilical port [30]. In 2007, Lima *et al.* performed a transgastric and transvesical simple nephrectomy, with the aid of an umbilical port, on six porcine models [31]. However, the specimens were not retrieved. The total surgical time was only 120 min, and there were no reported postoperative complications. Both experimental and human studies involving NOTES are summarized in Tables 1–3.

Technical challenges of NOTES & LESS

One of the major technical difficulties relates to instrumentation. In LESS, by definition, only a single site is used, and this could either be a multiport access device or multiple trocars through a single skin incision. This single site gives rise to a different viewing angle, crowding of instruments and impaired triangulation of dissecting and retracting instruments, thereby affecting exposure. Inserting a telescope and operating instruments through the same outlet reduces the optimum angle, hence affecting depth perception and vision, which could potentially increase the risk of a surgical error.

To overcome this challenge, refined instruments and purpose-built ports are required in order to improve triangulation and avoid instrument collision. The various types of ports used in NOTES and LESS range from a combination of ports of different diameters, extending from 2 to 12 mm. Examples of ports used are the TriPort™ (Olympus, Japan), the QuadPort™ (Advanced Surgical Concepts, Ireland) and the R-PORT® (Advanced Surgical Concepts, Ireland) [59]. These ports contain three to four inlets for working instruments (e.g., a 12-mm and two 5-mm channels). Other ports, such as the GelPort™/GelPOINT™ (Advanced Surgical, CA, USA), have been used for LESS and NOTES, which allows for variously sized trocars to be placed, with an insufflation port on the side of the device [35,60].

Improved optics, new durable materials and the miniaturization of electronic parts have led to further developments of flexible scopes and 'chip-on-tip' technologies. The EndoEye™ (Olympus Medical Systems) is a 5-mm rigid videoscope with a 30° or 0° lens, while the EndoEye LTF-VP™ (Olympus Medical Systems) has a flexible tip, which resolves the problem of overcrowding while allowing different viewing angles [7]. The telescope can be placed in a manner that allows the surgeon to obtain a conventional view of the field while positioned away from the operating instruments [61].

Newer technologies and better lenses have produced longer and thinner scopes, which reduces the clashing of instruments. Operative laparoscopes, which consist of a telescope and a working port, have been used in other specialties. Other newer scopes, such as the rigid EndoCAMeleon™ (Karl-Storz, Tuttlingen, Germany) , enables adjustment of the viewing direction between 0° and 120°, making intraoperative telescope changes unnecessary [62]. The incorporation of 3D optics, which has been successfully used in robotic systems, could also lead to better visualization.

The application of NOTES in urology has mainly used the vaginal route, with or without incorporating additional abdominal ports. However, as with LESS, without the necessary triangulation provided by additional ports, the procedure can be time consuming and technically demanding. A minilaparoscopic abdominal instrument provides the benefits of

Table 3. Experimental cases on natural orifice transluminal endoscopic surgery urological procedures.

Author (year)	Animal (n)	Natural orifice	Other ports	Procedure	Mean operative time (min)	Blood loss (ml)	Specimen retrieval route	Complications	Ref.
Sawyer *et al.* (2009)	Porcine (4)	Transurethral, transgastric	–	Partial cystectomy	–	–	–	None	[54]
Crouzet *et al.* (2008)	Porcine (1)	Transgastric, transvaginal	Abdominal	Bilateral renal cryoablation	83	<20	–	None	[55]
Humphreys *et al.* (2009)	Cadaver (4)	Transvesical	Holmium laser	Radical prostatectomy	120–240	–	Morcellated (1); transumbilical (1)	None	[56]
Krambeck *et al.* (2010)	Canine (6)	Transurehtral	Holmium laser	Radical prostatectomy	120	<50	Morcellated	Abdominal distension, fluid evacuation in abdomen secondary to intra-abdominal location of the canine prostate	[57]

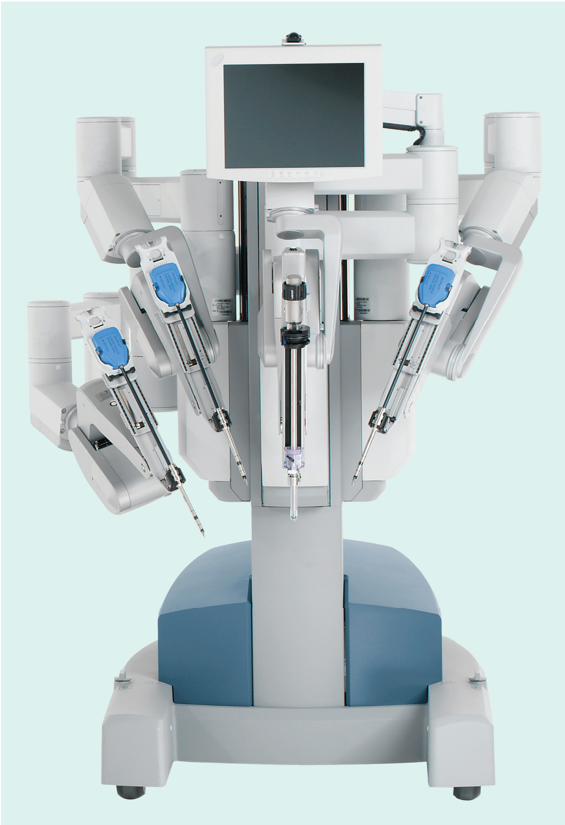

Figure 2. Patient cart with Instruments: da Vinci S® surgical system.

additional ports while preserving cosmesis by using smaller-caliber instruments, hence leading to smaller and less noticeable skin incisions. Porpiglia *et al.* performed five transvaginal NOTES-assisted minilaparoscopic nephrectomies using one 12-mm transvaginal port and three 3.5-mm abdominal ports and experienced no complications and minimal blood loss (mean blood loss: 160 ml; range: 100–200 ml) [38]. LESS nephrectomy, partial nephrectomy, donor nephrectomy and pyeloplasty are performed using 2- or 3-mm needlescopic ports [6,63].

An operating platform to suit the various NOTES procedures such as EndoSAMURAI™ (Olympus, Tokyo, Japan) , the TransPort™ (USGI Medical, CA, USA) multilumen operating platform and direct drive endoscopic systems have been developed [64,65]. NOTES requires a system that enables complex laparoscopic maneuvers while providing a stable operating field independent of the movement of the working arms – a feature that is particularly challenging with flexible instruments and endoscopes. This can potentially be overcome by using the TransPort [66]. This system provides four large working channels, including a port for an endoscope and three ports for large instruments. It has a steerable platform allowing for fine control of the distal scope while maintaining the remainder in a stable position. This feature is essential for delicate dissection in a narrow space [67].

Sotelo *et al.* and Kaouk *et al.* performed hybrid NOTES nephrectomies and later pure NOTES nephrectomies using TriPort and GelPort [26,35,37]. This gives more robust retraction and instrumentation, which is essential in nephrectomy. Perhaps the employment of robotics and 3D optics in LESS and NOTES may solve some of the current difficulties [68]. The use of robotic systems has been studied in porcine models. Box *et al.* employed the da Vinci S® (Intuitive Surgical, CA, USA) robot to perform a transvaginal nephrectomy [44]. Haber *et al.* performed robotic pyeloplasties, partial nephrectomies and radical nephrectomies in ten pigs [40]. One arm of the robot was employed in the transvaginal port while the other arm utilized the umbilical port. In three nephrectomies, technical problems were reported. These included the inability to reach the upper pole of the kidney and intracorporeal conflict between the laparoscope and umbilical robotic instrument. Modification in the design of the robotic systems may therefore be needed so that NOTES can be performed safely and efficiently [40,44].

Magnetic anchoring guidance system

To address the difficulties with tissue retraction during NOTES and LESS, the magnetic anchoring guidance system (MAGS) was developed by Caddedu and Scott in 2001 [69]. MAGS consists of a moveable magnet- or needle-lockable platform that is positioned intra-abdominally and stabilized by an external magnetic element placed on the abdominal skin [70,71]. Raman *et al.* performed transvaginal NOTES nephrectomies in two porcine models with the aid of MAGS; a scope was inserted via the vagina and a peritoneal incision was made under direct vision [72,73]. A MAGS camera was deployed through a prototype rigid access port via the previously created incision. It was positioned cephalad and lateral to the umbilicus. No issues with instrument collision were encountered and the MAGS camera provided adequate views throughout the procedure. The average operating time was approximately 140 min and blood loss was minimal. A limitation of the technique was that the coupling strength of the magnet appeared to be significantly reduced with greater distances, and hence could prove challenging in a larger subject (e.g., an adult human).

In conclusion, development of better operating platforms, enhanced high-definition 3D optics with reliable tissue retracting systems, multifunctional working ports, improved computer interfaces and robotic surgical instruments will aid in popularizing these MIS techniques.

Public perspective of LESS & NOTES

With the introduction of MIS, NOTES and LESS promise improved cosmesis, minimal or no scarring, reduced postoperative pain and length of stay and shorter recovery times. Despite multiple limitations, growing interest in these techniques has been generated. However, there is also a need to appraise the public's perceptions and expectations of the techniques, as this will determine the future course of these innovations. A recent review on public perceptions of 'scarless' surgery demonstrated an interest towards these techniques, with a preference for LESS over NOTES. Key factors such as safety and efficacy played an important role in the decision-making process [74].

For example, two studies by Lucas *et al.* and Olweny *et al.* looked at the importance cosmesis had on patients undergoing renal surgery and the factors that determined patient preference for a particular technique [75,76]. The majority of patients quoted surgical success and low complication rates as key factors in choosing a particular surgical procedure, while scarring was the least important consideration. Bucher *et al.* showed that cosmesis held only 3% importance, whereas cure ranked at 74% [77]. However, Bucher *et al.* also studied LESS and NOTES for cholecystectomy and found that if operative risk was similar, 87% would prefer LESS, 4% NOTES and 8% laparoscopy [77].

Tugcu *et al.* conducted a prospective trial comparing LESS simple nephrectomy and conventional laparoscopic nephrectomy [78]. All 27 patients in the LESS group were not only pleased by the cosmetic outcome (no visible scars), but also by the earlier return to normal daily activities (10.7 vs 13.5 days; $p < 0.001$). Kurien *et al.* concluded that LESS donor nephrectomy resulted in a shorter hospital stay and reduced requirements for postoperative pain relief compared with standard laparoscopy [79].

A recent study on women's perceptions of transvaginal NOTES showed that the main concerns were infection and dyspareunia. None of the patients would accept an increased surgical risk for better cosmesis and were unwilling to undergo LESS if the technique was associated with an increased risk of complications [80]. However, most case reports show that the majority of patients who have undergone transvaginal NOTES demonstrate no detrimental effects in sexual satisfaction [81,82]. Olakkengil *et al.* published a survey on the perspectives of laparoscopic donors toward transvaginal NOTES donor nephrectomy that also revealed postsurgical cosmetic appearance and absence of scars to be of minimal importance to most patients, regardless of age group [83].

Conclusion

Regardless of the multiple challenges ahead in achieving 'scarless' surgery, this concept has great potential to be the established practice of the future. Where it may previously have been thought of as a distant prospect or an impossible concept, surgeons will hopefully continue to push the boundaries of surgery fur-

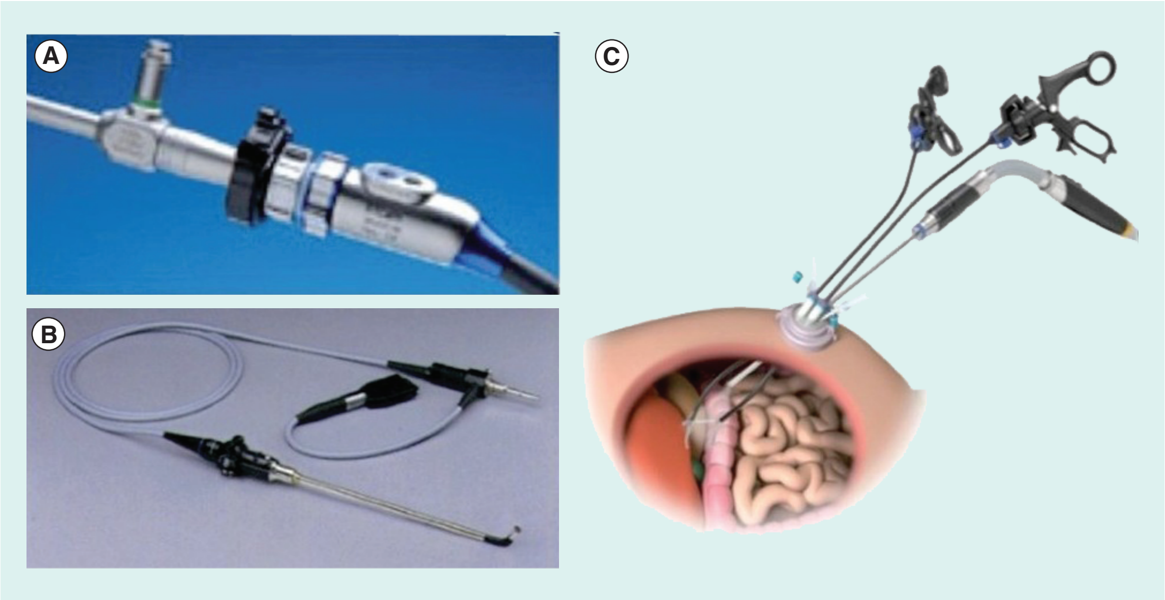

Figure 3. EndoEYE™ and EndoEYE LTF-VP™ with a deflectable tip and coaxial cable.(A & B) The integrated light cable is placed coaxially to the shaft of the telescope. This ensures that there will be reduced clashing of cables with intruments when working in a limited space. **(C)** The video laparoscope EndoEYE LTF-VP has a flexible tip which allows different various views to be obtained.
Reproduced with permission from [86].

ther, thereby creating a new reality in which ‘scarless’ surgery will become the norm.

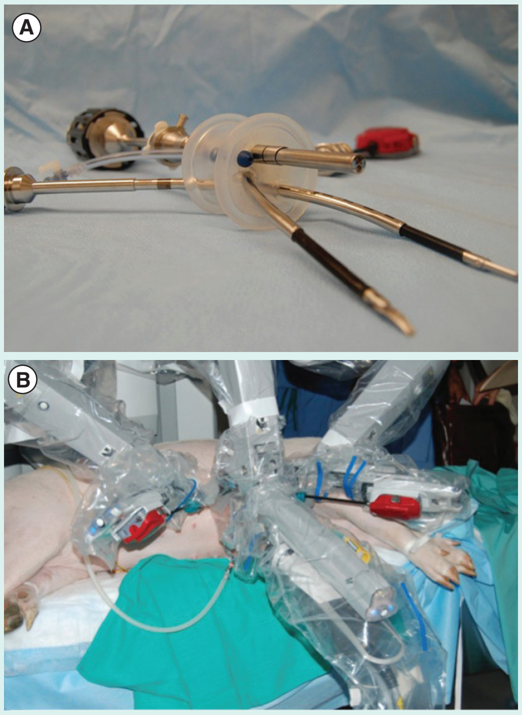

Figure 4. VeSPA robotic system (Intuitive Surgical, CA, USA) docked to a patient. This system contains curved trocars and flexible intruments specially designed for LESS. **(A)** Curved trocars and flexible instruments specially designed for laparoendoscopic single-site surgery. **(B)** Patient cart specially docked to the VeSPA robotic system (Intuitive Surgical, CA, USA). Reproduced with permission from [87].

Future perspective

The progress towards ‘scarless’ surgery hinges on the advancement of technology and the development of instruments and optics, which has been discussed above.

NOTES

Since its introduction in 2004, NOTES has not gained the same popularity as LESS [1]. The main challenges facing NOTES are the need for a stable surgical platform for the deployment and usage of instruments, thereby improving time efficiency and reducing the risk of intraoperative complications. Patients appear to be prepared to embrace this new technique in the future, so long as there is evidence to prove its effectiveness and safety. Dissemination of the surgical outcomes by the pioneers in NOTES, together with appropriate marketing, will perhaps pique the interest of the urological community and increase its popularity.

LESS

In the last 5 years, LESS has progressed tremendously, especially with the development of purpose-built laparoscopic instruments. Currently, the most popular and effective platform utilized is the transumbilical route. The approach is already reaping the benefits of new videocameras and flexible instruments, which can work smoothly through a single port, thus avoiding clashing of instruments. State-of-the-art chip-on-tip cameras, such as the EndoEye, enables the reproduction of high-definition images with the added benefit of making the instrument smaller and lighter. Future devices may employ the use of battery-powered wireless light-emitting diodes that can be placed in the abdomen and fixed by an extracorporeal magnet, similarly to the MAGS concept [75,76].

Novel surgical platforms for LESS are being introduced, such as the Single Port Instrument Delivery Extended Research (SPIDER®; TranseEnterix, NC, USA), a delivery system from a rigid platform with three 5-mm instruments that are curved inside the abdomen, providing a 360° range of motion and easier maneuverability and triangulation [84]. Flexible-tip rigid instruments provide the stability of a rigid tool while enabling improved maneuverability. The incorporation of ‘smart tools’ with multifunctional tips has generated considerable interest and will hopefully lead the way in popularizing LESS. These would also make it much easier to change the tip of the instrument without the need for removing the instrument from the port [84].

Robotic LESS

Robotic-assisted laparoscopic surgery is becoming increasingly popular and R-LESS is no exception. The 3D vision, articulating instruments and enhanced ergonomics of robotic systems, such as the da Vinci system (Figure 2), are some of the encouraging features that will help move the technology forwards. Bulky robotic arms, the risk of associated collision and the potential need for gaining surgical access to an anatomically remote area are potential problems that need resolving (Figure 3). However, the VeSPA (Intuitive Surgical), a robot built specifically for single-site surgery (Figure 4), has addressed some of the problems highlighted above. It has been successfully used in laboratory trials involving nephrectomy and pyeloplasty in porcine models and provides a wide range of motion, reasonable ergonomics and improved scope stability with reduced risk of instrument clashing [85]. Unfortunately, it does not address all of the issues, as it may lose articulation and can cause a pneumoperitoneum leak, which can affect safe surgical progress during the procedure.

Safe 'scarless' surgery performed by microrobots should no longer be regarded as science fiction. Advancements in robotic systems together with the miniaturization of devices are realistic developments and could potentially be in use in the next few years [88]. Technological advancements, refinements of current robotic systems, reductions in costs and further clinical studies will play a pivotal role in increasing the wider acceptance of LESS and NOTES.

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