Chapter 3
Current State of Laparoscopic and Robotic Surgery

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Abstract Minimally invasive surgical innovation has exploded in recent times. Currently, conventional laparoscopy is most widely adopted as the costs are relatively low. However, robotics and single port surgery are leading a revolution in surgery for wealthy health-care systems. We explore the historical and contemporary areas of this evolution.

Keywords Robotics • Laparoscopy • Surgery • NOTES • LESS • Single port

Key Points

- Laparoscopic surgery is becoming a gold standard across surgical specialities.
- Training in laparoscopy can be difficult and has a significant learning curve.
- Robotic-assisted laparoscopy is expensive but appears easier to learn.
- Single port surgery is novel, offering minimal scars; however, the advantages over conventional laparoscopy are unproven.
- Natural orifice surgery has limitation but has evolved significantly.
- Targeting and image guide surgery are close to adoption.

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H.R.H. Patel, J.V. Joseph (eds.), *Simulation Training in Laparoscopy and Robotic Surgery*,
DOI 10.1007/978-1-4471-2930-1_3, © Springer-Verlag London 2012

Historical Aspects

The Dilemma of the Nineties

Since the early 1990s, laparoscopic surgery has started to become a viable alternative to open surgery for a variety of urological indications (Table 3.1). In contrast to open surgery, where laparoscopic cholecystectomy quickly became the standard approach, there was not such a relatively easy to learn and frequent procedure in urology. Laparoscopic varicocelectomy, even with high success rates (97%), was not widely accepted compared to antegrade or retrograde sclerotherapy. Laparoscopic nephrectomy for benign indications is a rare indication, and in case of non-function hydronephrosis or end-stage stone disease may be really technically challenging. Conclusively, there was the argument that "laparoscopy was a nice procedure looking for an indication."

Nevertheless, pioneers were able to demonstrate the feasibility of laparoscopic ablative as well as reconstructive procedures [1–27]. Since there was a need to overcome the problems of restricted ergonomics particularly concerning endoscopic suturing, several authors focused on the geometrical aspects as well as other ergonomic factors influencing the adequate performance of laparoscopic surgery. Based on this, the first breakthrough was accomplished with the development of a stepwise training for suturing which led to laparoscopic prostatectomy with urethrovesical anastomosis [28–31]. European laparoscopists were able to meet the challenge of

Table 3.1 History of laparoscopy in urology

Indication	Author
Diagnostic of cryptorchidism	Cortesi [1]
Ureterolithotomy	Wickham [2]
Pelvic lymph node dissection	Schüssler [3]
Nephrectomy for oncocytoma	Clayman [4]
Radical nephrectomy for renal cell carcinoma	Coptcoat [5]
Varicocelectomy	Donovan [7]
Nephroureterectomy	Clayman [6]
Pyeloplasty	Kavoussi [8]
Retroperitoneal lymph node dissection	Hulbert [9]
Ileal conduit	Kozminski [10]
Pyelolithotomy	Gaur [12]
Radical cystectomy	Puppo [13]
Living donor nephrectomy	Schulam [14]
Radical prostatectomy	Schuessler [15]
Nephron-sparing excision	Janetschek [16]
Robot-assisted prostatectomy (da Vinci)	Abbou [20]
Radical cystectomy with Mainz-Pouch	Tuerk [22]
Ileal neobladder	Gill [24]
LESS nephrectomy (transumbilical)	Kaouk [26]
NOTES nephrectomy (transvaginal)	Box [27]

this technically difficult procedure, which has now been abandoned by their American colleagues [32–35].

The Diffusion of Laparoscopic Surgery in Urology

With longer follow-up, laparoscopy was able to prove similar oncological results as the open counterpart with respect to radical nephrectomy and nephroureterectomy [36–38]. Based on this, laparoscopic nephrectomy has become the recommended standard in the recent EAU guidelines 2008. The same has been achieved for laparoscopic adrenalectomy; however, this procedure is also performed by general surgeons. In this context, it has to be emphasized that the urological community has not achieved to conduct any prospective randomized multicenter study about the impact of any laparoscopic procedure. This is in contrast to our surgical colleagues who were able to prove the superiority of laparoscopic colectomy [39].

Early in this century, several groups started to perform laparoscopic radical prostatectomy [18, 32, 35]. In the year 2004, about 25% of all radical prostatectomies have been performed laparoscopically in Germany [40, 41]. However, there is still the debate about the superiority of this procedure over the standard retropubic open approach [42–44]. There is consensus that still the surgeon represents the most important factor of success [44]. Other laparoscopic reconstructive procedures, such as pyeloplasty or sacrocolpopexy, gained interest and some centers receive referrals particularly for these indications [45–47].

The Revolution of Robotic Surgery

This time, everything started in Europe with the first cases of robotic-assisted laparoscopic radical prostatectomies using the da Vinci device at the beginning of this century [19, 20, 48, 49] (Table 3.1). However, the procedure did not gain significant attraction mainly due to the enormous costs. Moreover, the patients did not demand the procedure. In the United States, the story of success of the da Vinci prostatectomy happened completely unexpected. The significantly improved ergonomics of the device with the surgeon sitting at the console using 3D vision and instruments with 7 degrees of freedom alleviated the introduction of laparoscopic surgery even for surgeons without any laparoscopic experience [50].

The most important factor represented the marketing strategy in the United States, where reimbursement was not a significant problem and “the robot” proved to be extremely attractive for the patient. Based on this, in 2009 almost 80% of all radical prostatectomies have been performed laparoscopically using the da Vinci device. Additionally, the robot is used increasingly for partial nephrectomies and pyeloplasties [51]. Again, there is not a single randomized study comparing open surgery to the robotic-assisted laparoscopy.

At the beginning, some specific difficulties of the da Vinci system have been encountered particularly for surgeons with laparoscopic experience [49].

Interpretation of Magnified Anatomy

The first problem for a laparoscopic surgeon represents the interpretation of the respective anatomical structures (i.e., the dorsal vein complex, bladder neck, vas deferens) seen under stereoscopic vision with a tenfold magnification. It proved to be difficult to adjust the new image to the known two-dimensional picture one has been used to over the last decade. The same applies to identify small vessels.

Lack of Tactile Feedback

The lack of haptic sense aggravates the dissection technique in this novel situation. Even if “standard” laparoscopy does only provide a minimal amount of tactile sensation, the effect of training and experience finally enabled the surgeon to have a certain haptic sensation, i.e., to assess the shape of the prostate, the severity of adhesions, and the strength of a suture or knot. The da Vinci system, actually, does not provide any tactile feedback. Nevertheless, the surgeon is able to compensate the missing tactile feedback by the improved stereoscopic vision (i.e., observing the deformation of tissue and the increasing tension on the suture). With increasing experience, one is able to estimate the applied strength on the suture when performing a knot. Nevertheless, working remotely without tactile feedback requires new surgical skills, solely based on visual inputs. This of course increases the mental stress during surgery.

Coordinated Interaction Between Surgeon and Assistants

The complexity of the operation itself requires proper assistance and instrumentation. In contrast to a laparoscopic nephrectomy or adrenalectomy, a laparoscopic radical prostatectomy cannot be performed as solo surgery. There is a need of retraction of the gland or adjacent structures. For vascular control, clips have to be placed, and sometimes suction is required to clear the operating field. All this has to be carried out by the assistant working under a deteriorated ergonomic situation.

Ergonomic Advantages of the da Vinci System

In robotic surgery, the working ergonomy for the surgeon is optimized due to the seated position, the clutch function, the tremor filter, and the in-line 3D vision. It is important to note that the sitting position alone does not improve the performance as shown by Berguer and Smith with the ZEUS device lacking the 7-DOF [52]. Moreover, at the da Vinci robot, the surgeon himself controls the camera. On the other hand, there is no tactile feedback, and the surgeon is very much dependent on optimal assistance (i.e., placement of clips). The working ergonomy for certain steps of the procedure can be even worse than during standard laparoscopy because of the robotic arms interfering with the manipulations of the assistant. The introduction of the fourth arm has improved this with respect to proper tissue retraction and exposure of the working field, but the situation for the assistant remains unchanged. Moreover, the mental stress on the surgeon at the console controlling five foot pedals and two arm handles (plus the fourth arm) should not be underestimated.

Newest Technological Developments

Recently, our attention has been focused on a modification of laparoscopy, the transition from multiple to single port access: Laparo-Endoscopic Single-Site Surgery (LESS). Reworked from an old technique, pioneered by gynecologists in the 1960s [53], they used an operative laparoscope, comparable to a rigid nephroscope, for tubal ligation. LESS has become attractive for multiple procedures [26]. In addition, abdominal targets have been approached in a transluminal way via natural orifices (i.e., mouth, vagina, anus, and urethra) leaving the patient without any scar [54]. Recently, NOTES (natural orifice transluminal endoscopic surgery) has been also tested for urological indications [25, 27].

Laparo-Endoscopic Single Port Surgery (LESS)

LESS is the standard term designated to avoid confusion and acronyms. It represents any minimally invasive intra-abdominal surgical procedure performed through a single incision/location, utilizing conventional laparoscopic or newly emerging instruments. Any procedures performed with an additional transperitoneal port should be referred to as hybrid LESS.

Raman et al. reported a successful experiment with a LESS nephrectomy on a porcine model and in human subjects [55]. Other small series show similar outcomes: live donor nephrectomy, renal cryotherapy, varicocelectomy, simple and even radical prostatectomy [26, 56–58]. About 100 abstracts describing LESS case report (ileal conduit, sacrocolpopexy, partial cystectomy) were presented at the WCE 2008 (Table 3.2) [20, 21]. At the WCE 2009, there were more series and comparative studies, revealing excellent cosmetics results and less pain over standard laparoscopy (Table 3.3) [20, 21].

The LESS technique involves main access ports via a single incision (2–3 cm). Articulated and pre-bent instruments allow for intracorporeal triangulation,

Table 3.2 Summary of less results at the World Congress on Endourology and SWL 2008 and 2009

Authors	Year	Procedures	Pts	LESS technique	Conclusions
White W. et al. MP18–16[a]	2008	Renal (29) and pelvic (22) surgery 8 retroperitoneal access	51[c]		"Its superiority as compared to traditional laparoscopy is currently speculative"
Desai M. et al. MP18–12[a]	2008	Transvesical prostate enucleation	15	R-Port ultrasonic shears	"Early experience appears encouraging"
Schwartz M. et al. VP8–02[b]	2009	Pyeloplasty (41)—7 hybrid	41		".... particularly advantageous in young patients more concerned with cosmesis"
Desai M et al. VP8–01[b]	2009	Renal (51), prostate (32), and others (11)	100[d]	R-Port + 2 mm grasper	"Improvement in instrumentation and technology is likely to expand the role of LESS"

[a]Abstracts presented at the 26th WCE & SWL 2008
[b]Abstracts presented at the 27th WCE & SWL 2009
[c]7 Renal cryoablations, 6 partial, 4 simple, 3 radical nephrectomies, 1 retroperitoneal mass ablation, 1 renal biopsy, 2 cyst ablation, 2 pyeloplasty, 3 nephroureterectomies, 3 varicocelectomies, 5 prostatectomy, 3 cystectomy, 1 ureteral reimplantation, 10 colposacropexy
[d]14 simple, 3 radical, 17 donor nephrectomies, 17 pyeloplasty, 32 simple

Table 3.3 Comparative study LESS versus laparoscopy presented at World Congress on Endourology 2008 and 2009

Nephrectomy 22 LESS vs. 11 Lap	33	Three adjacent 5 mm trocars	"LESS may offer a subjective cosmetic advantage"
Live donor nephrectomy 9 LESS vs. 9 Lap	18	R-Port	"LESS offers quicker convalescence and longer warm ischemia time"
Pyeloplasty 8 LESS vs. 8 Lap	16	R-Port+2 mm grasper	"LESS offers better convalescence and cosmetic benefits"
Partial nephrectomy 15 LESS vs. 15 Lap	30	n.a.Hybrid	"LESS offers equivalent comparative outcomes, significant less pain, and superior cosmesis"
Renal cyst marsupialization 15 LESS vs. 14 Lap	29	Homemade port from surgical glove	"LESS could be considered as primary treatment option"

despite adjacent position of trocars. Bent instruments are reusable and thus more cost-effective than articulated devices. However, the restriction on the degrees of freedom might result in a steeper learning curve than with articulating instruments. In comparison to the conventional laparoscopy, there are three main problems:

Triangulation: Instrument triangulation allows proper tissue retraction. Parallel placement of several instruments makes triangulation more difficult. However, using at least one flexible or curved instrument may offset the shafts adequately and accomplish a satisfactory degree of triangulation.
Retraction: The lack of additional assistant trocars limits correct exposition of structures. These can be achieved with intra-abdominal sutures affixed to the parietal peritoneum or transcutaneous sutures grasped and manipulated extracorporeally.
Instrument crowding: The parallel placement and proximity of instruments may result in their crowding. Clashing of instruments could be avoided by using bent, articulated, and different length instruments (i.e., obese and pediatric equipment). Moreover, recently developed laparoscopes (i.e., Endo-Eye, Olympus, Hamburg, Germany) offer a streamlined profile compared to the standard laparoscopic light cable entering the lens at 90°, where interaction with adjacent instruments is severely limited.

Transvesical LESS eliminates the contact with the peritoneal cavity and provides a direct inline exposition of the prostate obviating the need for mobilizing the bladder and developing the Retzius space. Desai et al. reported simple prostatectomy (three patients) and even robotic LESS radical prostatectomies [58].

Natural Orifice Transluminal Endoscopic Surgery (NOTES)

NOTES is defined as a surgical procedure that utilizes one or more natural orifices (i.e., mouth, anus, vagina, urethra), with the intention to puncture hollow viscera (i.e., bladder, vagina, colon, stomach), in order to enter the abdomen. Hybrid NOTES should be considered when additional instruments are placed transabdominally to assist the NOTES procedure [10].

Breda et al. for the first time described a vaginal extraction of a kidney following laparoscopic nephrectomy [59]. Gettman et al. reported a transvaginal hybrid NOTES nephrectomy in the porcine model [25]. NOTES developed significantly following the report of transgastric liver biopsy and cholecystectomy by Kalloo et al. in the animal model [60]. Since then, laboratory and clinical reports included cholecystectomy, tubal ligation, splenectomy, and appendectomy. Selection of best portal access needs to consider many factors: ease of access and closure, risk of infection, and relationship to the target anatomy (Table 3.4).

Transgastric: After advancing the endoscope into the stomach, the anterior abdominal wall is trans-illuminated and punctured with a needle or a needle-knife. A guide wire is advanced into the peritoneal cavity, a sphinctertome is inserted, and a gastric incision performed (comparable to PEG). Gastrotomy closure is accomplished either with endoclips or suturing devices [54]. Kalloo et al. evaluated the gastrointestinal tract to perform successful peritoneoscopy, liver biopsy, and gastric closure with clips in six pigs. At sacrifice, peritoneal cultures were negative [60]. A recent review described the first appendectomy on a human using the same technique.

Table 3.4 Different approaches to NOTES

Translumenal approach	Comments
Transgastric	(+) Well-known and safe procedure used to create PEG
	(−) Barriers still exist: standardization of gastrotomy site, endoscopic retroflection for upper abdominal procedures, spatial orientation, and optimal closure technique
Transvaginal	(+) Readily secure closure offered by standard surgical technique
	(−) Gynecologists claim postoperative infection, visceral lesions, infertility, and adhesions as conceivable complications. Other long-term potential problems could be dyspareunia, infertility, and the spread of preexisting endometriosis [48]
Transcolonic	(+) Well tolerated and offers easy access to multiple targets, even retroperitoneum and easy visualization of upper abdominal organs. Colon compliance could tolerate larger instrument and specimen retrieval
	(−) An incomplete closure of the colostomy site and subsequent peritonitis will be catastrophic
Transvesical	(+) Allows for a direct visualization of all intra-abdominal structures. The urinary tract is normally sterile and the risk of infection and intraperitoneal or retroperitoneal contamination should be less. Cystostomy sites are known to heal spontaneously by catheter drainage
	(−) Diameter of urethra can limit instruments introduction

Transvaginal: The posterior vaginal fornix is opened using a special trocar and the pouch of Douglas is reached, saline solution is injected, and a 2.7-mm endoscope is then introduced.

Gettman et al. described the first experimental transvaginal application of NOTES: a transvaginal nephrectomy on a porcine model [25]. Nowadays, the vagina is the most frequently used access route for clinical NOTES, but also criticized, because this may cause problems during intercourse.

Transcolonic: The site of access is 15–20 cm from the anus. A specially designed guide tube (ISSA) is inserted via the colon into the abdominal cavity after intraperitoneal instillation of a decontamination solution [61]. The technique of closure includes endoscopic clips and prototype stapling devices. Pai et al. performed in a porcine survival model transcolonic cholecystectomy. All animals survived postoperatively without signs of infection; however, on necropsy animals evidenced intraperitoneal adhesion and microabscesses [62]. Other applications included distal pancreatectomy and ventral hernia repair [61].

Transvesical: A flexible injection needle is advanced through the working channel of a cystoscope or ureteroscope to perforate the bladder dome. A balloon dilator is then passed over a guide wire to enlarge the cystostomy tract. Lima et al. [63] performed peritoneum cavity inspection, liver biopsy, and division of the falciform ligament in animal model. Bladder catheter was left 4 days and on necropsy after 15 days all cystostomies healed. The same authors performed in a porcine model a combined transvesical/transgastric hybrid NOTES cholecystectomy and a transvesical thoracoscopy access [64].

Limitation of Notes in Urology

At the WCE 2008 and 2009, a total of five abstracts described feasibility of transvaginal nephrectomy in human [27]. A recent study summarized the clinical application of NOTES analyzing 16 publications and highlighting great difficulties: 46 of 49 procedures required conversion to hybrid NOTES [65]. Lima et al. described a third-generation nephrectomy combining transgastric and transvesical NOTES. They concluded that this approach is technically feasible; however, there is no reliable method for removing the specimen [64].

This technique still lacks available instrumentation. Most of the reported surgical experience concludes that there is no technological advancement on this topic. The development of novel suturing and articulated instruments, flexible bipolar forceps, clips and staplers as well as the advent of manual mechanical manipulators for flexible accessories is outlined in Table 3.5. Moreover, the risk of the access-induced

Table 3.5 Available tools to perform NOTES in urology

Categories of instruments	Tools	Description/comment
Peritoneoscopes	Conventional gastroscope	(−) Inadequate illumination
		Floppy nature: Limited control of the tip
		Flexible instruments are ineffective for retraction and grasping tissue
		Not suitable for CO_2 insufflation (leakage and impossible pressure control)
	R-Scope (Olympus America, Center Valley, PA, USA)	Two elevators at the tip allow flexible instrument to be moved
NOTES platforms	Cobra (USGI Medical, San Clemente, CA, USA)	Two arms allow triangulation and rigidization
	USGI TransPort™ (USGI Medical, San Clemente, CA, USA)	18 mm Ø; 4 channels (7, 6, 4, and 4 mm)
		ShapeLock technology allows to be locked into desired shape, even when rigid distal section can be steered
Dissections	Spray Dissector (Ethicon Endo-Surgery, Cincinnati, Ohio)	Tip buried inside ceramic tip
Hemostasis	Flexible bipolar hemostasis forceps (Ethicon Endo-Surgery, Cincinnati, Ohio, USA)	Coagulation intraperitoneal vessel up to 4 mm in diameter
Clips	Triclips (Cook Endoscopy, Winston-Salem, NC, USA)	
	Resolution Clips (Boston Scientific, Natick, MA, USA)	
	Rotating clips (Olympus)	
Closure	T-tag	
	G-Prox tissue suturing system	

injury (i.e., peritonitis) has to be balanced with the complications of a standard laparoscopic or LESS procedure.

Future Directions

It has to be emphasized that the technical principle of laparoscopy and retroperitoneoscopy has proven to be safe and effective. Based on this, the technique has found acceptance in recent guidelines (Table 3.6).

New developments are only related to the modification of these minimally invasive techniques, be it by the assistance of a robot or using a single port. To further reduce the invasiveness of laparoscopy, surgeons have proposed limiting the number of abdominal incision (LESS) or eliminating them completely (NOTES). Best aesthetic results and less postoperative pain offered by LESS are clearly visible. Anyway only a long-term follow-up will assess functional and oncological results versus traditional laparoscopy. Moreover, the future will show how much a scar really matters. This may be different in certain parts of the world. In Brazil, LESS and NOTES have become very demanded by female patients. NOTES perfectly fit role of scar-free surgery and multiple routes of access have been shown safe and effective. However, only few studies on human have been accomplished, and many authors agree that the lack of applied instrument did avoid the determination of the real role of NOTES in clinical practice. Combination of robotics and augmented reality could be the next step for NOTES evolutions [66–68].

There is a need to improve the ergonomics of traditional laparoscopic surgery. The design of the da Vinci robot offers a variety of ergonomic advantages compared to pure laparoscopy. However, there are also some disadvantages, such as the lack of tactile feedback and restricted ergonomics for the assistant. The impact of these advantages depends also on the type of the procedure. There will be new robots on the market, providing even haptic sense, such as the project of the German Aerospace Research Centre on the construction of modular robot system for minimally invasive surgery (MiroSurge). In contrast to the da Vinci system, the robotic arms are controlled by micromotors allowing easy adjustment of the arms at the OR table (Fig. 3.1a).

Table 3.6 Differential indications for laparoscopic techniques in the year 2010

Indication	Laparoscopy	Robotic (da Vinci)	LESS
Adrenalectomy	First line	Not applied	Optional
Radical nephrectomy	First line	Not applied	Optional
Simple nephrectomy	First line	Not applied	Optional
Living donor nephrectomy	First line/optional	Not applied	Experimental
Partial nephrectomy	Optional	Optional	Experimental
Radical prostatectomy	Optional	First line/optional	Experimental
Radical cystectomy	Optional	Optional	Not applied
Pyeloplasty	First line	Optional	Optional
Sacrocolpopexy	Optional	Optional	Experimental

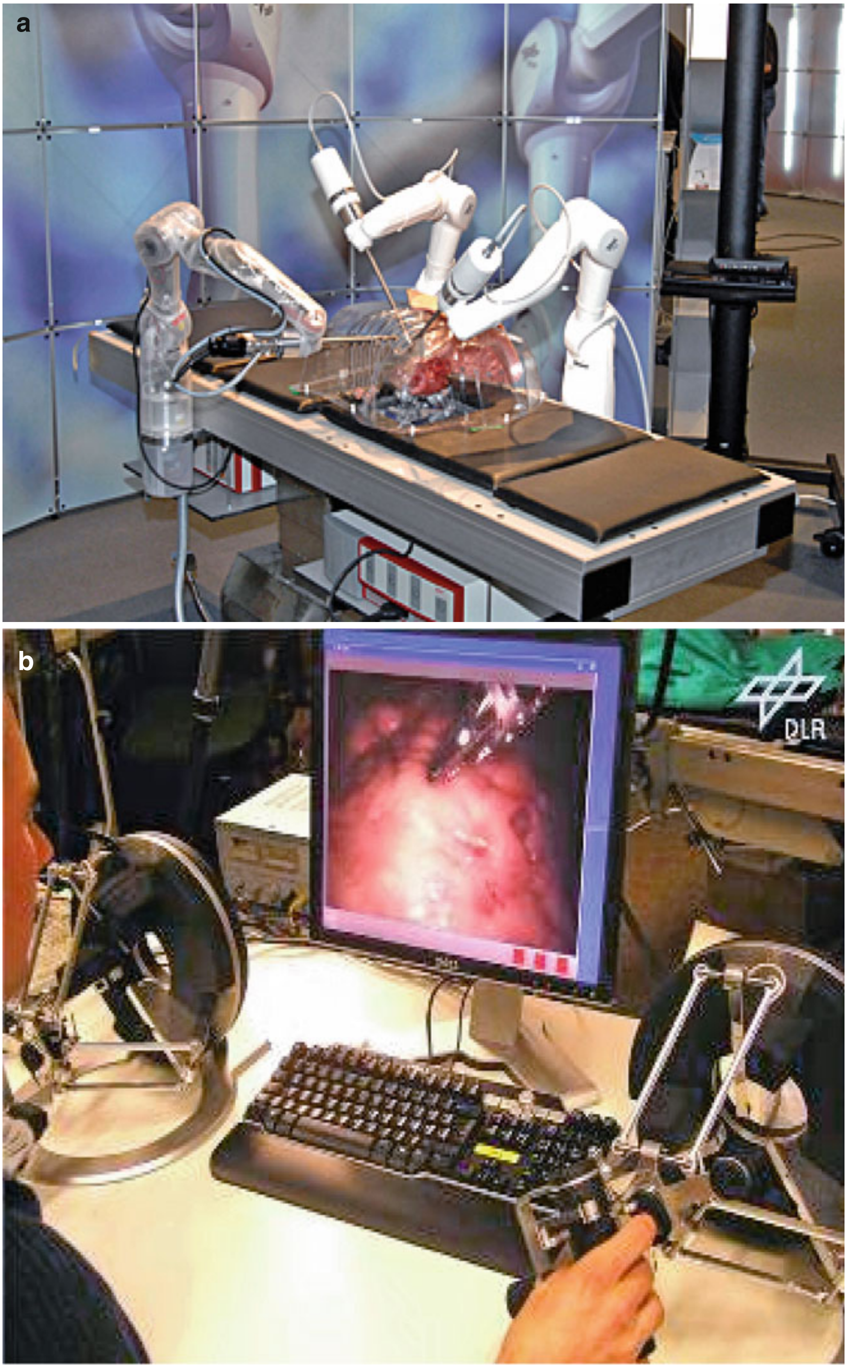

Fig. 3.1 New robotic device MiroSurge from the project of the German Aerospace Research Centre. (**a**) The robotic arms are controlled by micromotors, allowing easy adjustment of the arms at the operating room table. (**b**) The surgeon sits at a console using an autostereoscopic 3D monitor and two specially designed handles with integrated force feedback

The surgeon sits at a console using an autostereoscopic 3D monitor and two specially designed handles with integrated force feedback. The device has been a construction parallel to remote controlled robots used in space (Fig. 3.1b).

On the other hand, efforts should be undertaken by all manufacturers involved in the design of the operating theater to focus on the improvement of ergonomics according to the existing guidelines. This concerns the design of armamentarium and instruments, but also the OR table, platforms, OR chairs, arrangement of lines and cables. Some of this will include the perfection of already existing 7-DOF-devices for laparoscopy (i.e., equipped with miniaturized motors) [69, 70], the design of camera holders (i.e., compared to AESOP), and the improvement of LESS ports, providing completely steerable working channels for the flexible instruments to avoid any crossing of the instruments.

With all these new technical improvements, traditional laparoscopy will become much easier to perform. However, the success of the robot will not be stopped by any means. Similarly to the history of shock wave lithotripsy, cost arguments will become less important in the future. Every surgeon who successfully passed the learning curve of the da Vinci device never went back to open surgery. Of course experienced laparoscopists will still select cases for all three options (i.e., laparoscopy, LESS, robotic surgery; Table 3.6). On the other hand, the future of NOTES (i.e., with a transvaginal or transvesical access) still remains uncertain. It will be difficult to understand why a transvaginal access should be superior to a transumbilical port followed by a meticulous umbilicoplasty.

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