
Reproductive Surgery and Computer-Assisted Laparoscopy: The New Age of Subspecialty Surgery Is Here

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8.1 Computer-Assisted Reproductive Surgery: A Vision Fulfilled

Professor Ricardo Aziz, in his heartfelt Fertility and Sterility editorial of 2002, addressed the delicate topic of the role of reproductive surgeons in the age of in vitro fertilization [1]. It was a somber commentary that identified two main factors responsible for the epochal shift of many fertility specialists away from the surgical arena: on one side, the development of highly effective assisted reproductive technologies that rendered most tubal microsurgery obsolete; on the other, the success of advanced minimally invasive surgery, which changed the parameters by which the quality of reproductive surgery would be defined. However, the editorial's appeal to reproductive endocrinologists to continue to take responsibility for their patients' surgical needs was loud and clear: "*The American Society for Reproductive*

Medicine (ASRM) and the Society of Reproductive Surgeons (SRS) should not be timid in asserting their position as the homes of the world's finest reproductive surgeons. The efforts of the SRS to establish itself as the custodian of quality reproductive-organ surgery in women and men fits well with the very successful public campaign regarding 'prevention of infertility,' currently being undertaken by the ASRM. Reproductive surgeons and the SRS not only should serve as experts in the treatment of pelvic-factor infertility but should and will begin to take an activist and front-line role in improving the surgical care of men and women everywhere." To this end, one of the initiatives of the SRS was to partner with the American Association for Gynecologic Laparoscopists (AAGL) to sponsor the creation of postgraduate training opportunities in minimally invasive gynecologic surgery with a standardized minimal curriculum and a requirement for research. The AAGL/SRS Fellowship in Minimally Invasive Gynecologic Surgery initiative, inaugurated in 2001, has thrived over the past decade to graduate over 150 preceptees who have contributed in many ways to the advancement of minimally invasive surgery in this country and abroad. Thanks to such bold academic catalysts, general gynecologists with excellent technical skills in minimally invasive surgery are now present in most urban areas of this country, and access to this superior level of surgical care has improved. A regrettable shortcoming of this overall positive development is that the focus of most of these preceptorships has remained outside of the

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gynecologic subspecialties. As a consequence, at more than 10 years from Professor Azziz's appeal for the need of a strong and vocal reproductive surgery contingent in our health system, the number of reproductive endocrinologists offering the full range of endoscopic reproductive surgery to their patients is probably no higher than in 2002. Indeed, in spite of renewed appeals to promote the specialized role of reproductive surgeons in modern fertility care [2], a culture of disconnected care has somehow seeped into our subspecialty, whereby it is currently acceptable for complex reproductive surgery cases to be referred to minimally invasive general gynecology practices so they can have their procedures done laparoscopically. While the intention may be noble, the action is not always in the best interests of patients. Only a reproductive endocrinology subspecialist can effectively tailor the timing and extent of all medical, surgical, and ART interventions to each patient's unique reproductive endeavor. Take the common example of a 40-year-old nulligravida with borderline ovarian reserve, a new radiologic diagnosis of bilateral endometriomas, hydrosalpinges, and a sizable subserosal myoma. She is likely to receive two very different operations at the hand of a general gynecologist and of a reproductive endocrinologist. While laparoscopic excision of hydrosalpinges, stripping of endometriomas, and myomectomy would be reasonable procedures to consider, they would be the wrong choice in this particular case. Reproductive subspecialists epitomize the minimalist approach to gynecologic surgery: they would favor tubal interruption with biopsy and partial coagulation of the endometrioma and would avoid a myomectomy unless absolutely necessary. The aim of such an operation should not be complete eradication of all detectable pelvic pathology but rather preservation of ovarian reserve and swift triage to ART. When the ultimate goal is to potentiate the conception and birth of a healthy child, a deep knowledge of reproductive endocrinology and infertility is fundamental to effective reproductive surgery. It would therefore be hypocritical to pretend that the status quo of reproductive surgery in our country is adequate and sustainable.

Alas, we are a subspecialty on the verge of relinquishing an essential aspect of our expertise

in order to remain true to our values. That is to say that, as a subspecialty, we have long rejected open pelvic surgery and the unacceptable burden of adhesions that it entails [3, 4], yet the majority of us struggle to adopt advanced laparoscopy. Loss of three-dimensional (3D) vision, diminished haptic feedback, counterintuitive motion of the operative instruments, loss of wristed movements, tremor amplification, and unfavorable surgical ergonomics render advanced laparoscopic procedures difficult to master. Reproductive surgery entails extensive and precise suturing (as in myomectomy and tubal reconstructive surgery) and complex anatomical dissection (as in excision of advanced-stage endometriosis). Both tasks tend to be particularly challenging in a conventional laparoscopic environment. An uncompromised laparoscopic approach that replicates open microsurgical technique may be virtually impossible for all but the most skilled and practiced minimally invasive surgeons. The available ethical choices for reproductive specialists until recently were to learn and maintain expert conventional laparoscopic skills or to refer patients to minimally invasive gynecologists. The advent of computer-assisted laparoscopy has ushered in a new and appealing solution to this ethical and professional dilemma.

Advanced reproductive surgeries demand a sophisticated level of medical knowledge, surgical judgment, and technical skill. Computer-assisted laparoscopy, commonly known as robotic surgery, combines the intuitive operative environment of open surgery with the minimal invasiveness of laparoscopy. This technology may therefore enable willing reproductive surgeons to apply their specialized knowledge and microsurgical training toward advanced laparoscopic procedures. Reproductive surgeons were, in fact, the first in gynecology to recognize the benefits of robot-assisted surgery, while early prototypes were still in development, using the now discontinued Zeus platform to demonstrate the feasibility of robot-assisted laparoscopic tubal reanastomosis in 1999 [5]. The United States Food and Drug Administration (FDA) subsequently approved the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) for use in gynecologic surgery in 2005. This system and

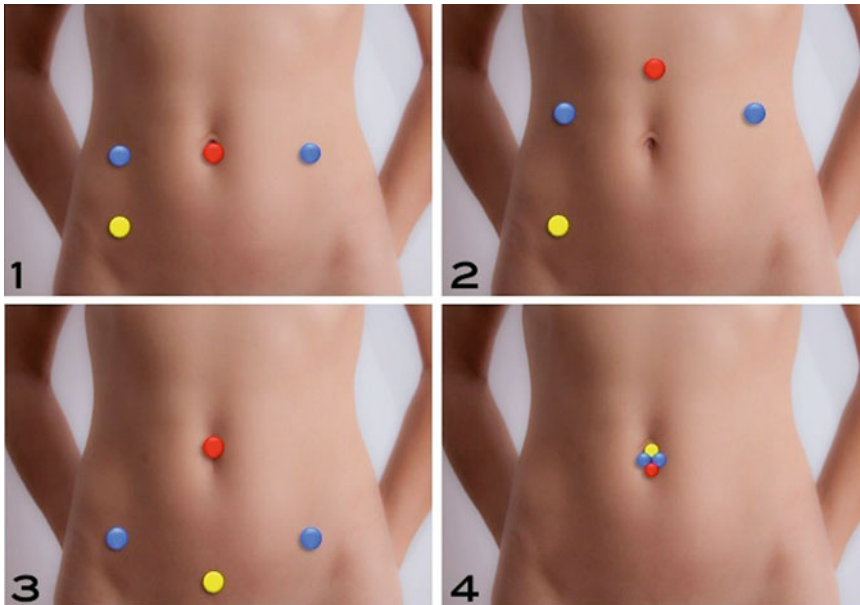


Fig. 8.1 Port placement for robot-assisted reproductive surgery. (1) Standard two-arm configuration with assistant port in the *right lower* quadrant. *Lower* assistant port makes needle exchange safer and allows conventional laparoscopic operation in the “vertical zone” if needed. (2) Standard two-arm configuration for large pathology: this is what we use

for our hybrid procedure (see Fig. 8.4); a third robotic arm is placed through a *left* side port in some of these cases. (3) Cosmetic configuration with suprapubic assistant port and low positioning of the bilateral robotic trocars. (4) Umbilical incision for single-port procedures. (Key: *red*=camera port, *yellow*=assistant port, *blue*=robotic ports)

its newer variations (da Vinci S, Si and Si-e) remain the only currently approved robotic surgical platforms for laparoscopic surgery available in the USA, although it is hard to imagine that competing technology will not become available soon.

Current robotic surgical systems consist of three main elements: a single or double remote surgeon’s console, a three- or four-arm patient-side robotic cart, and a vision cart. The surgeon employs a computer-aided interface to remotely control specially designed instruments through the passive bedside robot. Following standard abdominal insufflation, a primary cannula is inserted at or above the umbilicus. Subsequently, two or three dedicated 5-mm or 8-mm robotic instrument trocars plus an assistant port are placed as necessary for the planned procedure (Fig. 8.1). The arms of the patient-side robotic cart are connected to the cannulas. The primary surgeon controls an 8.5-mm or 12-mm binocular

laparoscope and up to three interchangeable robotic instruments while seated at the remote console. Any of the robotic arms can be re-assigned to the secondary console for training purposes or to allow the independent movement of all four arms for more sophisticated techniques. Most robotic instruments feature articulated tips, enabling 7 degrees of freedom in motion: grip, insertion, rotation, and pitch and yaw at both the elbow and the wrist. Floating hand controls at the remote console accommodate the surgeon’s thumbs and forefingers. These surgical systems use computer technology to overcome the fulcrum effect: they automatically reverse the pitch and yaw, such that the surgeon’s natural hand movements are translated into the precise, scaled movements of the robotic instruments. Pedals for activation of energy instruments are also integrated with the console.

Together, the full impact of these technological innovations is greater than the sum of its parts:

computer-assisted laparoscopy allows inexperienced users to complete complex laparoscopic tasks with less training, greater efficiency, and reduced operator workload compared to conventional laparoscopy [6–9]. In a seminal study by Stefanidis et al., medical students were tested on intracorporeal suturing in porcine Nissen fundoplication models [8]. The subjects were asked to place sutures using conventional laparoscopic instruments in one model and robotic assistance in the other (in random order). Robotic assistance significantly improved intracorporeal suturing performance and operating room safety and significantly shortened the learning curve. In addition, robotic assistance significantly reduced operator workload, as assessed by a validated National Aeronautics and Space Administration Task Load Index (NASA-TLX) questionnaire. This decrease in subjective mental and physical demand could improve physician performance and safety in challenging situations and release mental resources for unfamiliar tasks.

Studies comparing the learning curves for actual procedures using conventional computer-assisted laparoscopy will never be available. That is because such studies, in order to be meaningful, would have to replicate many conditions of the above work by Stefanidis on human subjects for entire operations. This would constitute a bioethical nightmare even in the most permissive of health systems. Several robotic surgery teams have reported their learning curves for specific operations. Not surprisingly, the results vary considerably by procedure and by the surgical experience of the team under study. Lenihan et al. showed that the operative time in robotic benign gynecologic cases (mostly hysterectomies) stabilized after a learning curve of 50 cases [10]. Payne et al. confirmed this finding, showing stabilization of operative time for robotic hysterectomy after 75 cases [11]. In contrast, a subspecialty gynecologic oncology team showed that proficiency for robotic hysterectomy with pelvic-aortic lymphadenectomy was achieved after 20 cases [12], and our own study on a high-volume team of reproductive surgeons could not identify any significant learning curve for robotic myomectomy [13]. Importantly, the prevailing success

of these robotic teams and the relatively short learning curves identified suggest that the rapid rise to proficiency afforded by computer-assisted laparoscopy in training tasks may also translate to real operations, where safety and reproducibility are paramount.

Computer-assisted laparoscopy brings two additional features that make it uniquely geared toward operating room safety and surgical education (1) enhanced ergonomics and (2) highly sophisticated simulation with objective evaluation. The field of surgical ergonomics has boomed following the introduction of advanced laparoscopy because the extreme ergonomic challenges it creates pose a threat to the health of both surgeons and patients alike. Surgeons may suffer from occupational injury due to musculoskeletal strain due to the physical maneuvers and unfavorable positioning required for laparoscopic pelvic surgery, whereas patient safety may be compromised by the high level of complexity found in advanced laparoscopic cases and a propensity toward distraction in the form of gaze disruption. These important themes will be explored in detail next.

To understand why the dangerous epidemic of musculoskeletal injury caused by laparoscopic surgery has remained relatively silent until recently, we must place it in the right cultural prospective. Physicians have historically thrived in their *deus ex machina* role, no matter how unfavorable the circumstances. From the carnage of battlefield hospitals throughout history, to the heroic fights against the Black Death, leprosy, and smallpox, to the sacrifices of radiation medicine pioneers, we are the cavalry and we know it. However, it seems this cavalry is not faring too well in laparoscopy.

Park and colleagues polled laparoscopic specialists in North America and reported that 86.7% of them had symptoms associated with musculoskeletal occupational injury [14]. The main predictor of symptoms was high case volume, whereas age, years in practice, and surgeon's height did not have an impact. A separate study by the same group reported that surgical assistants in laparoscopic surgery were also at risk for musculoskeletal occupational hazard [15].

These recent reports highlight the alarming prevalence of a well-known ergonomic flaw in the musculoskeletal requirements of conventional laparoscopy [16].

Computerized surgical platforms are a promising solution to the ergonomic challenges of laparoscopy because they eliminate the unbalanced posture and the neck and shoulder strain of the remote operators. While long-term benefits conveyed by the improved ergonomics of computer-assisted laparoscopy may be speculative for the time being, the need for a form of laparoscopy that is not crippling to the operator is self-evident. Furthermore, prolongation of surgical careers due to decreased occupational injury could permit more experienced senior surgeons to remain in the lead of their teams, to the advantage of patients and disciples alike. Absence of strain on the operator is also likely to allow a more homogeneous and predictable performance in the course of a long operative day or of a busy operative week.

Aside from the already-mentioned improvement of fundamental operative ergonomics, robotic technology eliminates the problem of gaze disruption. Gaze disruption, looking away from the immediate operating field, is a concept that is alien to classic surgery but implicit in the laparoscopic operating environment, where the visual and motor axes are no longer aligned. Advanced laparoscopy accepts gaze disruptions as a necessity, due to frequent instrument exchange, extracorporeal work, and occasional equipment troubleshooting. Such disruptions are more frequent than most realize: during laparoscopic cholecystectomy, 40 gaze disruptions occur in the main operator for every 15 min of operating time [17]. High-frequency gaze disruptions, a necessity introduced by laparoscopic surgery, constitute an interruption of task performance and can lead to surgical errors. A recent study in open cardiac surgery reported an average of 8.1 surgical flow disruptions per hour (about 20 times less than what was reported for laparoscopic cholecystectomy) and still found that they were associated with surgical errors [18]. Current computer-assisted laparoscopy is performed in a visually immersive environment where expert

surgeons can complete an entire procedure without ever taking their eyes out of the visor: gaze disruption in robotic surgery is practically nonexistent.

This last comment cautiously introduces unresolved bioethical issues in laparoscopic surgery that may become relevant to the diffusion of computer-assisted laparoscopy. Although digital simulation for laparoscopic surgery has been available for some time, the level of technological innovation and the amount of research and development that is going into simulation for computer-assisted laparoscopy is understandably much higher, given the computerized nature of the platform. Currently, virtual reality simulators are focused on replicating specific repetitive tasks that prepare the surgeon to achieve optimal economy of motion and safe remote handling of the surgical robotic cart. Because current computer-assisted surgical systems involve simultaneous use of all four limbs, achieving and maintaining the seamless integration of the surgeon's body with the remote console's multiple operating interfaces requires time, much like driving a car. Simulators not only facilitate and optimize this stage of training by eliminating the need for a dry lab or an animal facility (and certainly, live patients) but also provide an incredible variety of skill exercises and a fully objective and detailed technical feedback for the benefit of the trainee and the teacher (Fig. 8.2). Full-procedure virtual reality simulation for computer-assisted laparoscopy is an area of active research and development that is sure to provide useful products in the very near future. However, even current skill-focused simulation for computer-assisted surgical systems has been so remarkably impactful that it is considered by most experts to be essential for the future of robotic surgery training [19, 20]. Thanks to the reality, and promising future, of digital surgical simulation many of us prognosticate the obsolescence of that scary adage that summarizes the tired dogma of surgical education: "*see one, do one, teach one.*" We believe that the new adage "*see one, digitally simulate until you can replicate what you saw—only then do one, teach one*" is more in keeping with modern surgical ethics and just plain smarter.



Fig. 8.2 Integrated digital simulation for computer-assisted surgical system. Clockwise from *left to right*: original surgical console with computer “backpack”

installed, frame of actual digital simulation and final score screen with itemized performance commentary. (Photographs courtesy of Intuitive Surgical, Inc.)

In summary, it is critical to realize that computer-assisted laparoscopy is still laparoscopy but with a powerful user-interface that enhances safety and reproducibility. If the main reason for the quasi-demise of reproductive surgery was the impracticality of universally transposing microsurgical quality to the minimally invasive arena, then the entry of robotic technology into our operating rooms should mean a rebirth of our subspecialty surgery. In the next sections of this chapter, we analyze the literature calling for a shift away from laparotomy for virtually all fertility-sparing operations and will highlight the applications of computer-assisted surgical platforms in this critical movement.

8.2 Robot-Assisted Laparoscopic Myomectomy

Uterine fibroids, though not always problematic, are a common finding in women of reproductive age. Women frequently seek treatment for fibroids due to abnormal uterine bleeding, bulk-related symptoms, or poor reproductive outcomes. Indeed, submucous and intramural fibroids have been associated with subfertility, implantation

failure, and miscarriage [21]. Fibroids have also been associated with later obstetrical complications such as increased risk of preterm delivery, fetal malpresentation, and labor dystocia [22, 23]. Evidence supporting hysteroscopic resection of submucosal myomas to improve fecundity or ART outcome is limited to small retrospective studies and uncontrolled trials, but the results are compellingly in favor of this treatment [22]. Prospective randomized trials supporting the excision of intramural fibroids for reproductive indications alone, however, are lacking. This amplifies the challenge of determining whether or not myomectomy could benefit a patient’s path toward conception and healthy childbirth and makes it all more important to involve a reproductive endocrinologist in such decisions. When surgery is deemed advantageous, reproductive specialists should naturally favor a minimally invasive approach to myomectomy whenever possible.

Fortunately, both traditional laparoscopic myomectomy (LM) and robot-assisted laparoscopic myomectomy (RM) offer a safe and effective minimally invasive option for the treatment of symptomatic uterine fibroids in women who desire future childbearing. Compared to abdominal

myomectomy (AM), LM is associated with lower estimated blood loss and hemoglobin drop, decreased postoperative pain, shorter hospital stay, quicker return to normal activities, and fewer overall complications [24]. Three randomized trials additionally suggest improved fertility following LM compared to AM [25–27]. Despite early concerns regarding the integrity of the myometrial repair, the risk of uterine rupture following LM is quite low—between 0.0 % and 0.25 % [26, 27]—and compares favorably to the rate of rupture following AM, which ranges from 0.0 % to 4 % depending on the series [28–30]. The rate of uterine rupture following RM was similarly reassuring (1.1 %; 95 % CI 0.3, 4.7) in a recent multicenter study involving 127 pregnancies and 92 deliveries in 107 women [31].

Unfortunately, conventional LM is a technically demanding procedure, and despite the many compelling statistics in favor of minimally invasive myomectomy, the procedure remains largely underutilized. A recent survey of Canadian gynecologists reported that only 12.7 % of those performing myomectomy in their practice used LM more than 50 % of the time [32]. While not all myomectomies can be laparoscopic, we predict that robotic myomectomy (RM) will reset the modern standard of care such that most women requiring myomectomy will eventually benefit from a minimally invasive approach to the procedure.

The first series on RM was reported by Advincula and colleagues in 2004 [33]. Since then, multiple studies have demonstrated the safety and efficacy of the procedure. Perioperative outcomes are excellent and mirror those of traditional LM [34]. Case-matched comparisons between patients undergoing AM or RM show that RM is associated with lower mean blood loss, fewer complications, and shorter hospital stay [35–37]. In general, RM takes longer than AM and costs more than LM. An important finding across multiple centers, however, is that reproductive surgeons trained in RM are capable of addressing difficult fibroid cases with a tumor burden that would typically call for laparotomy.

A representative study from the Cleveland Clinic compared perioperative outcomes for 393

abdominal myomectomies, 93 laparoscopic myomectomies, and 89 robotic myomectomies and found no significant differences between LM and RM in terms of blood loss, operative time, or hospital stay despite a significantly larger tumor load in the RM group (223 vs. 97 g, $p < 0.001$) [37]. Compared to AM, RM required significantly longer operative time (181 vs. 126 min, $p = 0.003$), but hospital stay, blood loss, and hemoglobin drop were all significantly reduced despite a similar tumor load (226 vs. 263 g, $p = 0.360$). The authors remarked that robotic assistance allowed many would-be abdominal myomectomies to be performed laparoscopically and concluded that RM might improve utilization of a minimally invasive approach to myomectomy.

Our own experience with RM has been similarly transforming. There is no question that expert laparoscopists can complete complex multiple myomectomies without resorting to laparotomy, but it is noteworthy that reproductive endocrinologists can reproduce such results with the aid of computer-assisted laparoscopy. This was illustrated in our study comparing short-term outcomes from 174 RM and 115 LM performed by separate reproductive endocrinology and minimally invasive gynecology teams [13]. Tumor load was substantial in both groups. The median number of fibroids removed was 2 (range, 1–21) in the LM group compared with 3 (range, 1–16) for RM. Median weight of the fibroid specimens was 201 (range, 1–1,473 g) vs. 159 (range, 8–780 g). Median diameter of the largest fibroid was 7.5 (2.2–16.5) vs. 7.3 (3.1–13.8 cm) in the LM and RM groups, respectively. Perioperative outcomes were excellent for both techniques, but median operative time was significantly longer for RM (191 min vs. 115 min). Barbed suture was used in most LM cases but only in 5 % of RM and may have contributed to the observed difference in operative time. More importantly, this study illustrated that an experienced reproductive endocrinology team could address complex laparoscopic myomectomies with computer assistance and achieve perioperative results comparable to those of an experienced minimally invasive gynecology team. This feat deserves serious consideration despite the increase in operative time.

Since the inception of the gynecologic robotic surgery program at Brigham and Women's Hospital in 2006, our team has performed over 500 robotic myomectomies with no conversions to laparotomy. Most of these are performed as same-day surgery with only a small minority of patients requiring overnight observation or inpatient admission. We strongly believe that our fastidious preoperative evaluation has promoted and upheld our 0 % conversion rate to laparotomy.

High-quality preoperative imaging for fibroid mapping is essential to preoperative and intraoperative planning. The main goals of preoperative imaging are to (1) assess the size and location of all myomata relative to the endometrial cavity, (2) rule out diffuse adenomyosis, and (3) identify lesions suspicious for sarcoma. Pelvic ultrasound is just as useful as magnetic resonance imaging (MRI) in the mapping of smaller uterine masses [38]. However, ultrasound is less useful for larger uteri because this modality often fails to adequately define the relationship between fibroids and the endometrial cavity or other important anatomic landmarks. This information is critical for optimizing uterine incisions during the case and for avoiding unintended entry into the cavity or cornual regions. MRI with and without gadolinium enhancement is therefore preferred in such situations. MRI also has a high specificity for identifying adenomyosis and, together with serum LDH, for predicting the presence of leiomyosarcoma [39, 40]. It is essential to identify both of these conditions preoperatively because neither diffuse adenomyosis nor sarcoma would be amendable to conservative excisional therapy by laparoscopy.

In general, candidates for RM at our program are patients with a largest fibroid dimension under 15 cm and with fewer than 15 total fibroids (Fig. 8.3a, b). RM is not offered to patients with diffuse adenomyosis or with an endometrial cavity obscured by fibroids on MRI or to most women whose uterine fundus extends above the umbilicus on physical exam (this depends on adequate space for trocar placement, uterine mobility, and the perceived ability to debulk the uterus laparoscopically before docking the robot).

Our surgical protocols for RM transpose classic AM technique to the laparoscopic environment.

This concept is appealing from a reproductive specialist's perspective where accurate myometrial repair and uncompromising microsurgical technique may conceivably lead to superior reproductive and obstetrical outcomes. While we acknowledge that other centers' RM techniques may vary subtly from ours, we offer here a step-by-step description of our RM technique from the moment the patient is in the operating room. This explanation and the accompanying figures are also intended to serve as a general guide for robotic operating room procedures and port placement strategies, which may be applied other robot-assisted reproductive surgeries in addition to RM.

Once in the operating room, the patient is positioned in dorsal lithotomy with both arms tucked parallel to the body in surgical toboggans. Protective foam padding is secured over the face, arms, and thighs. A pelvic examination is performed under anesthesia for final planning of the best surgical approach and trocar placement. An oral-gastric tube is placed to drain the stomach. After the vagina and abdomen are sterilely prepared, a Foley catheter is inserted to drain the urinary bladder and a uterine manipulator with a channel for chromopertubation is placed.

Port placement configuration is estimated preoperatively but may be finally determined after abdominal insufflation. Initial entry can be gained in the left upper quadrant or umbilicus before determining the final placement for the camera arm, which may be placed several centimeters cephalad to the umbilicus or even just inferior to the xiphoid process for very large uteri. Either a 3- or 4-arm configuration may be used depending on whether a third robotic instrument will be needed for uterine positioning (Fig. 8.1, sec. 1). Dilute vasopressin (20 units vasopressin in 40–60 mL normal saline) is injected into the myometrium overlying the first fibroid targeted for enucleation. The robotic patient-side cart is then "docked" at a 30-degree angle to the left side of the operating table, and all robotic trocars and instruments are correctly positioned and inserted under laparoscopic guidance.

After the vasopressin has taken its effect, we create a transverse incision over the myoma using either robotic harmonic shears or a flexible CO₂

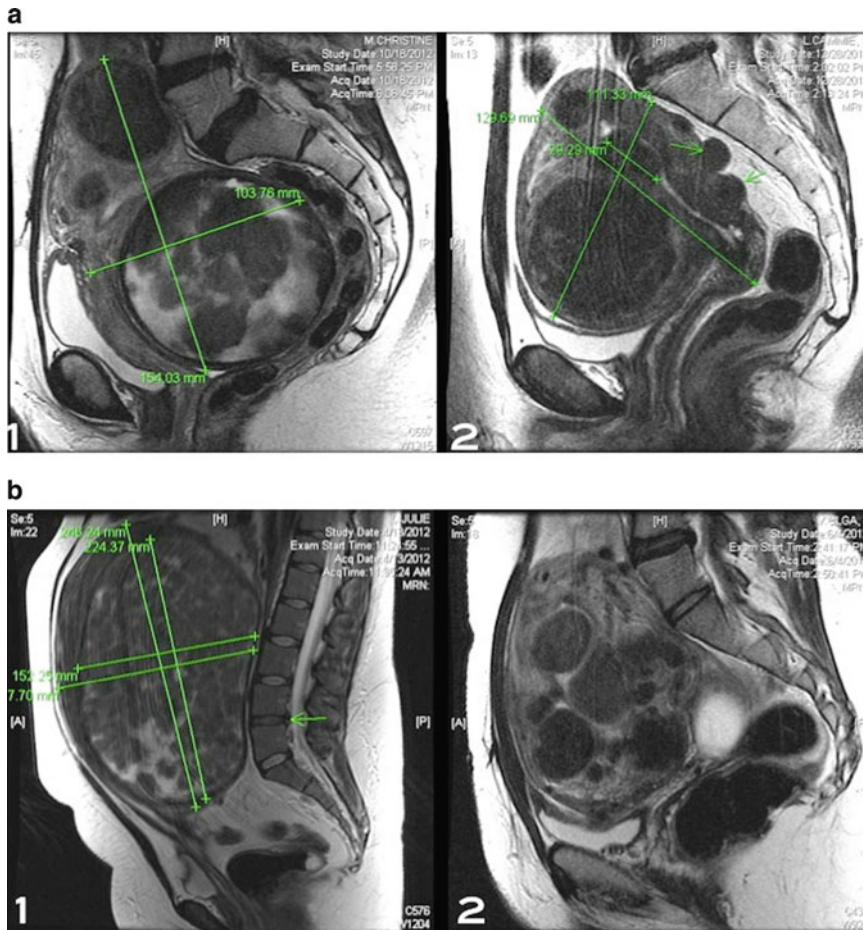


Fig. 8.3 The laparoscopic threshold. (a): (1) and (2) show MRI images (T2-weighted sagittal projections) of typical surgical candidates for RM variant at our center. Myomas in the 1–10 cm range are effectively enucleated with this technique in our experience. (b): MRI images (T2-weighted

sagittal projections) from patients who are not currently considered good candidates for RM at our center. (1) The tumor (22×15 cm) is too large to be safely addressed. (2) The uterus is studded with too many myomata to address laparoscopically (“bag of marbles” appearance)

laser fiber, which have minimal thermal spread, and restrict the use of monopolar robotic shears to postreproductive patients desiring uterine preservation. We prefer transverse uterine incisions when possible because they are more easily repaired than longitudinal incisions and are less likely to transect the arcuate vessels providing blood flow to and from the fibroid and its surrounding myometrium. Robotic tenaculum forceps are used to grasp the fibroid for stabilization, positioning, and traction during the enucleation. A robotic Maryland or other bipolar fenestrated grasper may provide counter-traction if needed,

and robotic instruments may be interchanged between arms if this will facilitate dissection around challenging angles.

The bedside assistant has access to the field via a 5 mm or 12 mm port. The smaller port size may be used if the surgeon and assistant feel comfortable passing sutures (and morcellating) through the primary camera port. Enucleated fibroids are placed into the anterior or posterior cul-de-sac or in the paracolic gutter if very large. A running count of the free fibroids is maintained throughout the case. If multiple small fibroids are removed, there we secure them by passing a

suture (polyglactin 910 or polypropylene) on a Keith needle through each of them so that they are not lost in the abdomen before morcellation.

Suturing is performed with a mega or large robotic needle driver in Instrument Arm 1 and a large needle driver in Instrument Arm 2. We strive to remove as many fibroids as possible through each myometrial incision so as to minimize the extent of trauma to the uterus as a whole. Careful preoperative review of the MRI is essential to maximizing the benefit of each incision. Immediate repair of the uterine incisions after fibroid enucleation minimizes blood loss. Chromopertubation may be performed to test for entry into the endometrial cavity. We repair any visible endometrial defect with a running suture of 3-0 poliglecaprone 25 to decrease the risk for intrauterine synechiae or fistula formation. We currently use self-retaining barbed suture, namely Quill (Angiotech, Vancouver, BC) or V-Loc (Covidien, Mansfield, MA), for almost all RM repairs—especially those involving very large myomata. The robotic platform also facilitates intracorporeal knot tying when using conventional suture (polyglactin 910): we still prefer this technique for delicate repairs, such as those of retroperitoneal or cervical myomata. We close the uterine serosa with a baseball stitch using barbed suture or 3-0 poliglecaprone 25. If using a 4-arm configuration, the robotic tenaculum may be used to optimally position or stabilize the uterus during the repair.

The robot is then undocked, and the fibroids are morcellated through either the assistant port site (suprapubic or right lower quadrant) or the umbilical port site. The latter avoids enlargement of assistant port site when a 5-mm trocar is in place, and a standard 5-mm laparoscope can be used through one of the 8-mm robotic ports. We rarely morcellate with the robot docked. After complete hemostasis is assured, Interceed (Ethicon, Somerville, NJ) is placed over the serosal repairs as an adhesion barrier.

Several variations in our RM technique allow for an added degree of individualization toward the patient and pathology at hand. Hybrid (conventional plus robotic) laparoscopic myomectomy consists of conventional laparoscopic enucleation

of the largest one or two fibroids followed by swift docking of the patient-side robotic cart for repair of the defect and subsequent enucleation and repair of the smaller fibroids (Fig. 8.4). The hybrid technique works best for myomata >10 cm in diameter, as conventional laparoscopy allows for easier operation in the upper abdomen, which is required for some large myomata (Fig. 8.1, sec. 2). A rigid 10-mm laparoscopic tenaculum also allows the operator to exert more traction than the articulated robotic tenaculum and provides a degree of tactile feedback during the enucleation. Hybrid RM should only be performed by surgical teams that are comfortable with conventional laparoscopic myomectomy techniques and seamless docking of the robot (Fig. 8.1, sec. 2).

Though our standard port configuration for RM uses small abdominal incisions, many patients find the resulting upper abdominal scars to be less desirable than those which may be more readily concealed below the waist line [41]. We have therefore developed a “cosmetic approach,” which allows us to respect this patient preference in women with a smaller tumor load (Fig. 8.5). This technique uses a 3-arm configuration with lower placement of the operating ports and the use of a suprapubic assistant port (5 mm or 12 mm) as discussed above (Fig. 8.1, sec. 3). Incisions for the 8-mm robotic trocars are placed about 3 cm medial and just cephalad of the iliac spines. Of note, the lower and more lateral placement of the robotic arm ports changes the angle of the instruments with respect to the target anatomy and consequently makes the necessary surgical maneuvers more challenging than with conventional (higher) port placement. Use of a 15-cm primary trocar elevates the camera arm an extra 3 cm away from the abdomen and adjacent instrument arms. Assistance from the suprapubic port is facilitated by the use of 25-cm minilaparoscopy instruments to reduce external collisions with the robotic camera arm.

Finally, advanced robotic teams may be able to offer an even more cosmetic approach with robotic single incision laparoscopic robotic myomectomy SIL-RM (Figs. 8.6 and 8.1, sec. 4). We recently reported on two successful cases

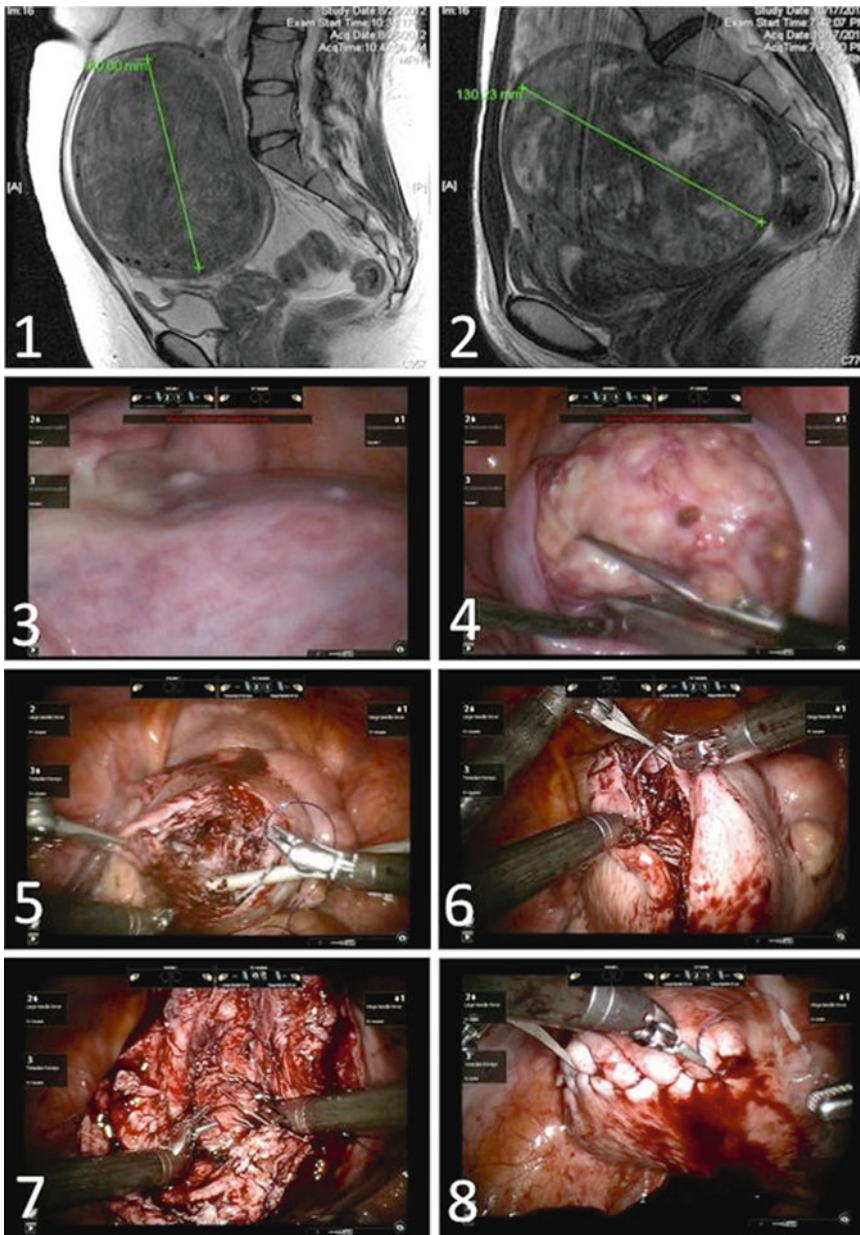


Fig. 8.4 Hybrid robotic myomectomy. (1) and (2) show MRI images (T2-weighted sagittal projections) of typical surgical candidates for the hybrid RM variant at our center. Myomas in the 10–15 cm range are more effectively enucleated with this technique in our experience. (3) Standard laparoscopic camera is used to guide enucleation. (4) The surgeon creates a transverse incision over the myoma using a harmonic scalpel; the 10-mm laparoscopic tenaculum is used to manipulate the fibroid during

enucleation. (5) The robot is docked onto the patient and the repair of deep defects is swiftly carried out with barbed suture. (6) This case had two incisions performed during the conventional laparoscopy phase: the smaller one is quickly closed. (7) Attention is brought to the second incision and closure in layer is performed. (8) Suturing the serosal layer with barbed suture is safe provided that an infolding suture line is created (baseball stitch). Smaller myomata are addressed later in the operation

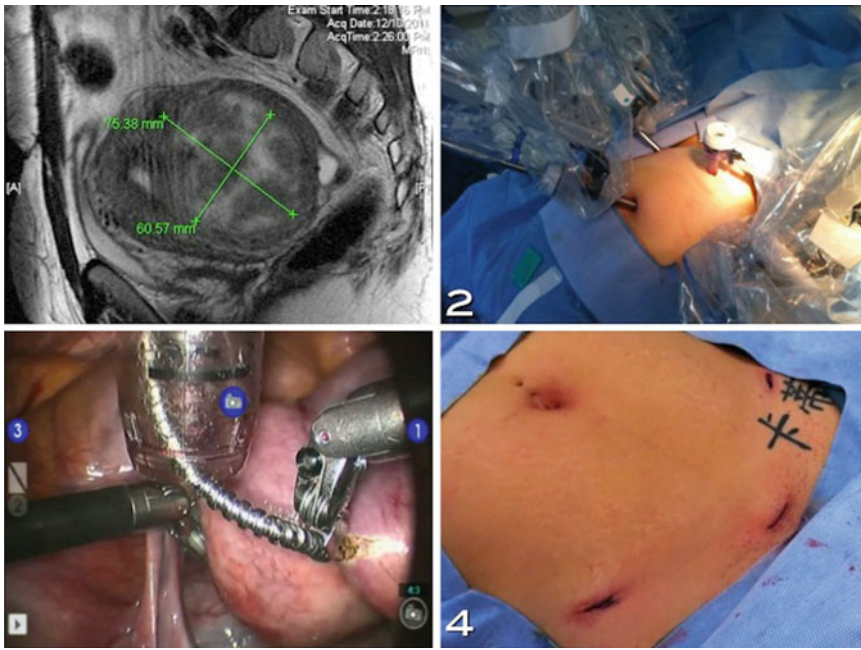


Fig. 8.5 Cosmetic robotic myomectomy. (1) MRI image (T2-weighted sagittal projection) of typical surgical candidates for cosmetic RM variant at our center. Myomas in the 1–8 cm range are effectively enucleated with this technique in our experience. (2) The bedside assistant has

access to the operative field via a suprapubic assistant port. (3) The suprapubic assistant port is adequate for assistance, passage of needles and passage of the laser fiber. (4) When the abdomen is desufflated all three lower incisions fall below the level of the anterior-superior iliac spines

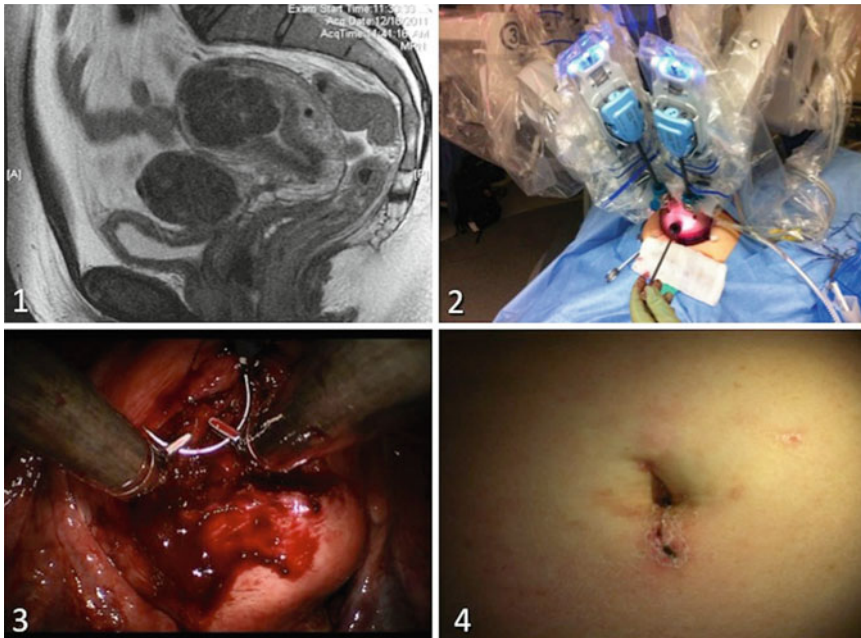


Fig. 8.6 Single incision robotic myomectomy. (1) MRI image (T2-weighted sagittal projection) of typical surgical candidates for single incision RM variant at our center. Myomas in the 1–6 cm range are effectively enucleated with this technique in our experience. (2) The GelPOINT device allows placement of four laparoscopic channels,

including an assistant port (most cephalad). (3) The coaxial technique is made possible by the wide yaw of the 8 mm robotic instruments. (4) At 2 weeks from surgery results are already cosmetically remarkable. The best cosmetic results are certainly obtained in women with a significant abdominal pannus and deep umbilicus

utilizing this ultra-minimally invasive technique [42]. Apart from reducing the number of visible incisions, clinical advantages of robotic SIL-RM may include decreased postoperative pain and reduced risk of herniation and superficial vessel and nerve injury. Successful application of the SIL-RM technique involves (1) use of Instrument Arms 1 and 3 with Arm 2 folded around the main column of the patient-side cart and (2) a periscope “up” approach with a 30-degree robotic laparoscope to allow room for a 5-mm assistant port in the GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA).

Regardless of the type of RM performed, we prefer to see patients for a postoperative visit approximately 2 weeks after surgery to ensure that their recovery has been uneventful. Patients may resume intercourse as early as 2 weeks postoperatively but are specifically counseled to use contraception for a minimum of 3 months to allow the myometrium time to heal prior to pregnancy. We recommend that patients with a large intramural myomectomy or with a myomectomy that has reached the endometrium (even without entering it) undergo a cesarean delivery. In patients of reproductive age whose endometrial cavity was entered during RM, we recommend a follow-up outpatient hysteroscopy to rule out intrauterine synechiae.

In conclusion, while the choice of AM raises ethical questions when LM is feasible, a technically uncompromised LM that is the exact replica of an open microsurgical myomectomy is arguably one of the most technically demanding pelvic operations ever conceived and is likely to remain out of the practical reach of most subspecialists. Several studies now indicate that RM is as safe and effective as conventional LM. Ultimately, every laparoscopic surgeon—advanced or basic—has a personal threshold for open surgery. With proper case selection, however, RM may be able to replace AM in most instances and should offer an appealing alternative to LM for most reproductive surgeons. As reviewed here, RM generally requires additional operating room time compared to AM and additional resources compared to conventional LM. However, we find it likely that many reproductive endocrinologists

would accept these as reasonable investments toward a quality surgical procedure that raises their laparotomy threshold, adheres to classic microsurgical principles, and facilitates seamless subspecialty-level reproductive care for their patients.

8.3 Tubal Reanastomosis

One in five women under the age of 30 at the time of tubal sterilization later regrets her decision [43]. Even so, tubal reanastomosis in the age of assisted reproduction appears to be going the way of the dodo [44]. This is most unfortunate. Reproductive endocrinology and infertility practices should be able to offer this technique as an option for women with no other apparent cause of infertility and for whom multiple gestations are not acceptable or assisted reproduction is otherwise not desired, ethically acceptable or attainable. In a cost-conscious environment where neonatal intensive care costs related to multiple premature deliveries vex our health system, our conscience—or third-party payers—should prompt more of us to offer surgical sterilization reversal over in vitro fertilization when appropriate. In order to compete with assisted reproduction, this operation should be minimally invasive, effective, and competitively priced.

Tubal reanastomosis generally aims to reestablish the patency of a 1–2 mm lumen. Classic microsurgical techniques employ an operative microscope and ultrafine sutures to produce an anatomically correct, tension-free anastomosis. A select group of reproductive surgeons have been able to replicate this microsurgical technique laparoscopically and have reported clinical results comparable to those of open microsurgery [45]. Still, most reproductive surgeons would agree that the technical challenges posed by laparoscopic tubal reanastomosis are formidable. The rate of conversion to laparotomy was 5 % even at one high-volume center [46]. Surgical case volume is an issue while developing and maintaining one’s laparoscopic skill set for tubal reanastomosis—and perhaps even more so when teaching this relatively rare procedure.

Table 8.1 Pregnancy and delivery rates within 2 years of RTR

Patient age (and number)	Number and % with at least one pregnancy (95 % CI)	Number and % with at least one delivery (95 % CI)
≤35 (<i>n</i> =33)	<i>n</i> =30; 91 % (76–98 %)	<i>n</i> =29; 87.9 % (72–97 %)
36–39 (<i>n</i> =32)	<i>n</i> =24; 75 % (57–89 %)	<i>n</i> =21; 65.6 % (47–81 %)
40–42 (<i>n</i> =16)	<i>n</i> =8; 50 % (25–75 %)	<i>n</i> =7; 43.8 % (20–70 %)
≥43 (<i>n</i> =12)	<i>n</i> =4; 33 % (10–65 %)	<i>n</i> =1; 8.3 % (<1–38 %)
Total (<i>n</i> =93)	<i>n</i> =66; 71 % (61–80 %)	<i>n</i> =58; 62.4 % (52–72 %)

Age stratification according to the Belgian Register for Assisted Procreation

Note: 4/97 patients were lost did not complete the 24 month follow-up and were not included in the final analysis

Redrawn from Caillet et al. *Fertil Steril*. 2010, with permission

Computer assistance could help to improve the practicality and diffusion of this valuable laparoscopic technique.

Several teams have published on the safety, feasibility, and effectiveness of robotic tubal reanastomosis (RTR). Surgeons at the Cleveland Clinic first described the procedure on the now discontinued Zeus robotic system [47] and later compared RTR with the Da Vinci robotic system (*n*=26) to microsurgical reanastomosis via outpatient minilaparotomy (*n*=41) [5]. Pregnancy rates (61 % robotic vs. 79 % minilaparotomy), ectopic rates, and hospitalization times were not significantly different, but operative times were longer and direct procedure costs were higher in the RTR group. Return to work however was shorter by 1 week in the RTR group. Dharia-Patel et al. performed a similar prospective cohort study (RTR vs. open reanastomosis) with comparable results [48].

Although most surgeons counsel patients based on data from their practice, we find that the best published data to counsel women regarding their age-dependent chance for success following RTR is from Caillet et al. [49]. This large retrospective cohort study analyzed pregnancy outcomes for 97 women aged 24–47 years (median age 37 years) who underwent RTR. It should be noted that all women had normal follicular phase FSH levels and normal male partners' semen analyses. The overall pregnancy and live birth rates at 2 years after surgery were 71 % and 62 %, respectively. Nearly 88 % of women <35 years old and 44 % of women aged 40–42 years delivered at least one child during the follow-up period (Table 8.1).

We perform RTLRL by a modified version of the procedure described by Degueudre et al. [50]. The basic steps of this technique, illustrated in Fig. 8.7, have been published elsewhere [51]. Briefly, a uterine positioning system with chromopertubation capability is placed. Laparoscopic port placement follows the same scheme illustrated above for our cosmetic RM. Placement of a third robotic arm is not possible in this configuration: when more complex anatomy or a less experienced team are involved, a more conventional robotic port placement is recommended. This way Prograsp robotic forceps can be operated through the third instrument arm for improved exposure and tissue stabilization. Side docking of the robotic patient-side cart allows easier access to the suprapubic assistant port and the uterine positioning system. Robotic instruments include Potts Scissors and MicroBipolar forceps during the initial step of tubal stump preparation and two Black Diamond Micro Forceps during suturing. Ultrafine (1:5) downscaling is recommended for da Vinci S and fine downscaling (1:3) for da Vinci Si. Dilute vasopressin is injected into the proximal and distal segments of the mesosalpinx to allow optimal hemostasis. Following mobilization and partial amputation of the tubal stumps, patency of the proximal stump is confirmed by chromopertubation. We employ a graduated 3–5 French endoscopic retrograde cholangiopancreatography (ERCP) cannula as a tubal stent to provide anatomic orientation and to help identify the tubal lumen during suture placement. The mesosalpinx is approximated with 1–2 sutures of 6-0 Vicryl in order to take the tension off the reanastomosis line.

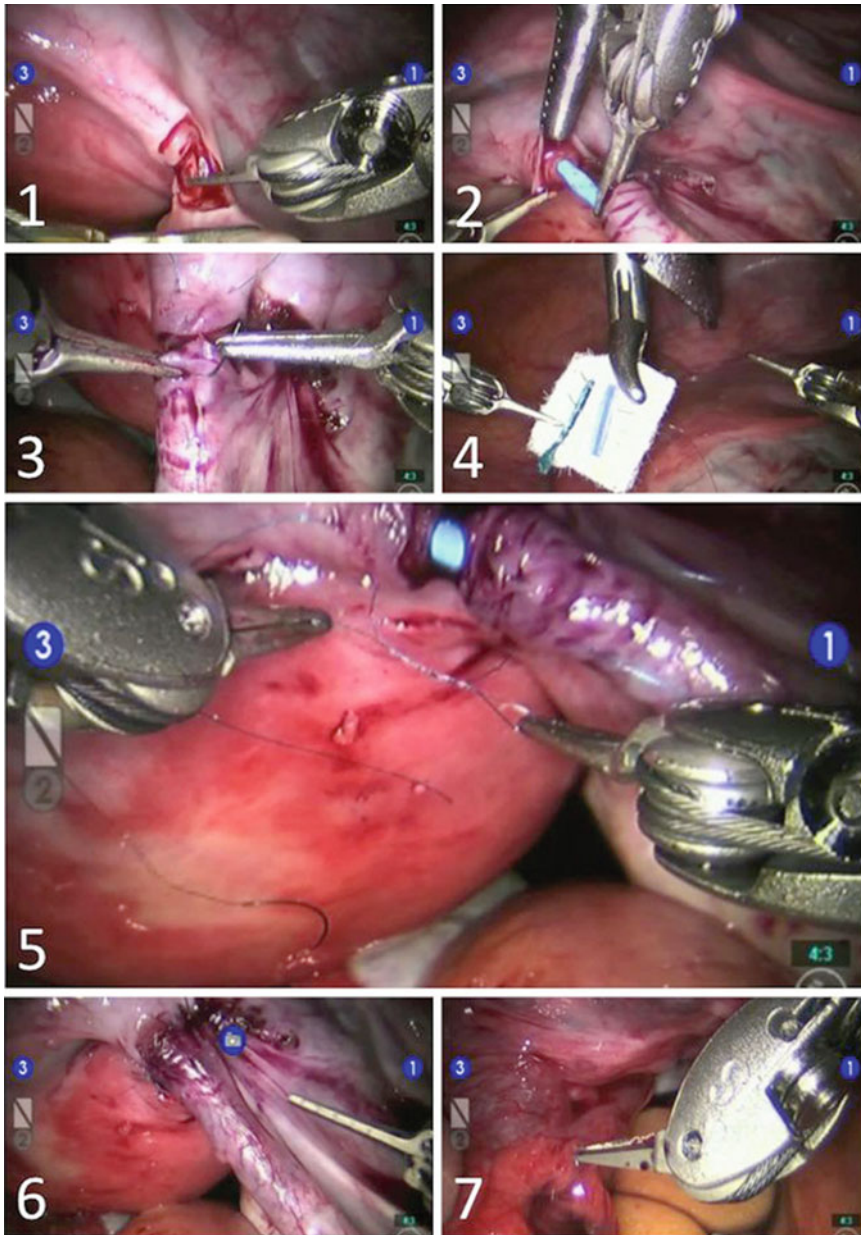


Fig. 8.7 Robotic tubal reanastomosis (RTR). (1) The proximal and distal tubal segments are identified and mobilized with microbipolar forceps and Potts scissors. (2) The tubal segments are cannulated and stabilized with a graduated ERCP catheter. (3) The tubal segments are reanastomosed with interrupted sutures of 8-0 Prolene

using Black Diamond forceps. (4) Needles are passed on surgical patties under complete visualization to avoid needle loss. (5) Sutures are serially tied over the guide catheter, resulting in an anatomically correct, tension-free anastomosis as shown in (6). (7) Tubal patency is demonstrated by chromoperturbation

The tubal stumps are then approximated next with four interrupted 8-0 Prolene sutures placed at 3, 6, 9, and 12 o'clock in the muscularis and mucosa, with great care to place the knots on the

outside of the lumen. The serosa is reapproximated with interrupted 8-0 Prolene sutures if needed. Chromoperturbation must confirm tubal patency at the completion of the procedure.

In conclusion, laparoscopic tubal reanastomosis, with or without computer assistance, is a highly specialized surgery. The ASRM advises that it should only be attempted by those who are very facile with laparoscopic suturing and have extensive training in conventional tubal microsurgery [52]. Several authors have demonstrated that RTR is safe, effective, and reproducible. Our unpublished experience with conventional and RTR techniques over the past 15 years indicates that robotic surgery greatly facilitates the learning and successful completion of this challenging operation on the part of our trainees. Well-designed studies addressing this specific question may never become available, due to the fact that advanced laparoscopic surgeons with access to robotic technology are unlikely to continue training future generations of surgeons on conventional laparoscopic reanastomosis. Moreover, the popularity of long-acting reversible contraception, hysteroscopic sterilization, and assisted reproduction will likely diminish the opportunities for individual surgeons to acquire and maintain expertise in tubal reanastomosis. Therefore, the use of computer-assisted technology could gain even greater importance for the future of this minimally invasive procedure.

8.4 Surgical Management of Endometriosis

Nowhere is the direct involvement of reproductive endocrinologists in the operating room likely to be more impactful as in the management of severe pelvic endometriosis in women who desire future childbearing. Indeed, this is one of the most controversial areas of reproductive surgery. While laparoscopic destruction of minimal to mild endometriosis may improve fecundity [53–55], benefits are less clear for advanced stage endometriosis [56–61]. Reproductive endocrinologists must carefully weigh the benefits of every surgical act against the risks of iatrogenic harm in the context of the patient's specific symptoms and her immediate and future reproductive plans.

By far the most complex aspect of the surgical management of this condition is the special case

of cystic ovarian endometriosis (endometrioma). Depending on the presentation, fertility status, and age of the patient, excision of an endometrioma can be mandated or contraindicated. A stubbornly radical approach to recurrent endometriomas in a nulligravida in advanced maternal age may only temporarily improve the symptoms of this chronic inflammatory condition, but at the same time condemn her to procreate with donor oocytes. On the other hand, the assumption that a persistent 5-cm complex cyst in a young IVF patient is a benign endometrioma may cause delayed diagnosis and dissemination of an ovarian malignancy. For these reasons, reproductive endocrinologists must be able to deliver expert first-line surgical treatment for endometriomata in women of reproductive age, from indication to execution.

Ovarian cystectomy involves “stripping” of the cyst wall from the normal ovarian tissue while causing minimal trauma. Dissection of the cyst wall away from normal ovarian cortex can be technically challenging at laparoscopy, particularly for endometriomas. These cysts lack a true cyst wall but have instead a pseudocapsule derived from stretching and inflammation of a portion of ovarian cortex. As such, stripping of an endometrioma always causes a loss of primordial follicles. Moreover, the deepest portion of the pseudocyst is often found in close association with the vascular hilum of the ovary. This can contribute to more serious functional ovarian loss if thermal energy is employed to achieve hemostasis [57, 58, 60].

There are no published studies specifically describing the use of computer-assisted surgery in the management of endometriomas. In our experience, computer assistance facilitates ovarian cystectomy by offering 3D visualization of tissue planes and by facilitating the precise application of traction vectors during stripping procedures. We preferentially use cold sheers or CO₂ laser to incise the ovarian cortex overlying the tumor when necessary [62]. Robotic excision of endometriomas is performed by careful use of opposing forceps. In cases where preservation of ovarian reserve is essential, we employ a recently described technique of partial stripping (removing approximately 85 % of the pseudocapsule

area) followed by ablation of the deepest area of the endometrioma, overlying the hilar vessels. Donnez and colleagues found that this hybrid excision–ablation technique was not associated with a postoperative decrease in antral follicle count and rarely resulted in the finding of normal ovarian follicles at histologic evaluation of the excised cyst wall (2 %) [63]. Similar results were reported by Muzii and Benedetti Panici in their version of this technique employing electrocautery [64]. This group likewise modified their technique for surgical management of endometriomas after finding that normal primordial ovarian follicles are most concentrated at the base of the endometriotic pseudocyst, overlying the ovarian hilum [65]. They also histologically mapped the inner wall of the endometrioma and found that it is covered by endometriotic tissue on 60 % of the surface, with a mean value of maximal depth of endometriosis penetration of only 0.6 mm [66]. Given the distribution of normal and pathologic ovarian tissue and the reassuring reports on postoperative ovarian reserve described above, we agree that a conservative excision–ablation approach to benign ovarian cystectomy is conceptually ideal.

Our version of this technique—adapted for the robotic system—involves the use of a flexible hollow fiber CO₂ laser device (Fig. 8.8). The flexible fiber allows full use of the 7 degrees of freedom of the robotic system, which results in highly precise and very safe use of this energy form [62]. An 8-mm assistant port delivers the flexible fiber (contained within an armored introducer) into the abdominal cavity and still allows use of 5-mm assistant instruments through the same port. A robotic needle driver is locked into the tip of the fiber introducer. When necessary, photonic energy or cold shears are used to create a primary incision in ovarian cortex until the endometrioma is exposed. Precise plane dissection between the pseudocyst wall and the ovarian stroma is mostly achieved by blunt technique providing appropriate traction. Occasional areas of adhesion are lysed by utilizing low energy setting of the laser. Following excision, the ovarian bed is irrigated and hemostasis is established. Small bleeders can be coagulated with the help of the divergent laser beam, which

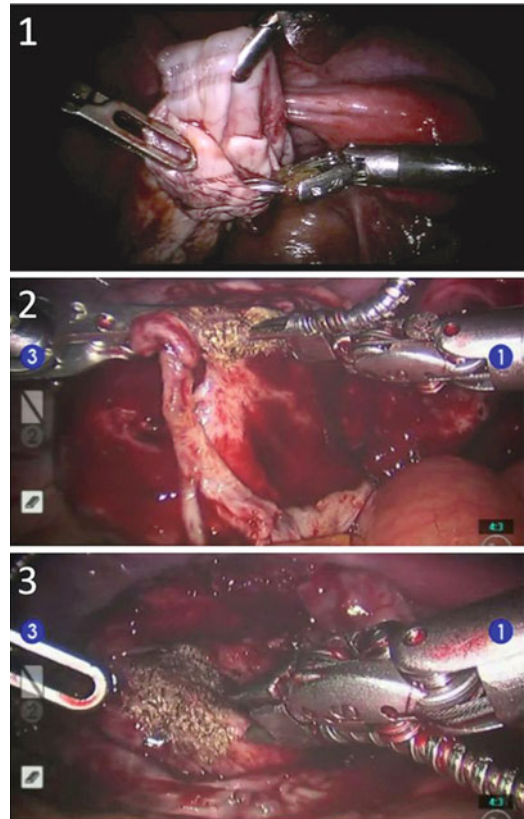


Fig. 8.8 Robotic excision of endometrioma with partial stripping and coagulation of the base. (1) A cosmetic port setup as the one described in Fig. 8.1, sec. 3 is adequate for this operation: the assistant can help during the stripping by immobilizing the pseudocyst. (2) A flexible CO₂ laser fiber is used to precisely excise the large portion of the endometrioma cleaved off of the ovarian stroma. (3) The base of the endometrioma, overlying the ovarian hilum, is left in place: its internal surface is ablated with CO₂ laser

provides a superficial coagulative effect when held at a distance from the target. If necessary, localized figure of eight sutures of 6.0 Vicryl or similar absorbable suture are used to control focal bleeding. Hemostatic matrix or other local hemostatic agents should also be considered as a worthwhile alternative to electrocoagulation in cases of more persistent bleeding. In general, no other form of energy is needed to secure hemostasis, thus aiding in ovarian tissue preservation. The ovarian defect can be gently approximated with 3-0 Vicryl in a continuous, unlocked, baseball-stitch. We wrap the completely hemostatic ovary in an adhesion barrier at the end of this procedure.

In summary, standard laparoscopic techniques for ovarian cystectomy carry inherent reproductive risks and this is particularly true for endometrioma, where surgical technique and level of execution can make a big difference [67]. Thus, a search for alternative methods to effectively remove these ovarian cysts while minimizing risks of recurrence and ovarian failure seems reasonable. Research on clinical outcomes following computer-assisted conservative adnexal surgery is needed.

Reproductive surgeons are well aware that endometriomas are often found in the context of other features of advanced-stage endometriosis, such as dense adhesions distorting peritoneal and even retroperitoneal anatomy, as well as deep infiltrating endometriosis. Several case series describe the successful application of robotic surgery to severe endometriotic disease involving the bladder, bowel, and ureters [68, 69]. A retrospective study published by a team of high-volume minimally invasive surgery experts compared robotic and conventional laparoscopic treatment of endometriosis [70]. Both methods were equally safe. Although operative times were longer in the robotic group (191 vs. 159 min), the authors were positively impressed with the overall value of robotic assistance in managing advanced-stage endometriosis: they reported no conversions to laparotomy in nine cases of stage III–IV endometriosis. Computer-assisted surgery may enable more reproductive endocrinologists to offer advanced endoscopic procedures to their patients in instances when the alternatives might have been laparotomy or referral to a nonreproductive specialist. The caveat with severe endometriosis is that no degree of computer assistance can ever substitute for strong fundamentals of surgical anatomy, technique, and judgment.

8.5 Surgical Fertility Preservation: Ovarian Transposition, Ovarian Tissue Cryopreservation, and Transplantation

It is now well documented that treatment for malignancy and certain benign medical conditions may threaten a woman's fertility. Reproductive tract

tumors may require removal of the uterus with or without the ovaries, while many other conditions may require gonadotoxic radiation or chemotherapy, which can damage a woman's ovaries or uterus and place her at risk for infertility and premature ovarian failure. Reproductive endocrinologists have a critical role to play in the pretreatment counseling of women facing gonadotoxic therapies and should work diligently with oncologists and other medical providers to ensure that these patients are fully aware of their options for fertility preservation. Some—but not all—women will be candidates for oocytes or embryo cryopreservation. When feasible and successful, these techniques provide a reasonable level of hope for patients to produce genetic offspring following gonadotoxic therapies. The advantages of these techniques are that they take advantage of established assisted reproductive technologies. The disadvantages are the time required for controlled ovarian hyperstimulation and oocyte retrieval (and possible delay in cancer treatment), the direct cost to the patient, the possibility that no pregnancy is achieved with the finite number of gametes or embryos cryopreserved, the fact that ovarian steroidogenic function is not preserved, and the exclusion of prepubertal girls. Surgical fertility preservation techniques, both proven and experimental, may address some of these problems. In this section, we address fertility-sparing surgery from the perspective of a reproductive surgeon. We believe that providers should be aware of these options, their indications, and limitations. This brief overview of surgical fertility preservation illustrates the feasibility of laparoscopic techniques and highlights the potential application of computer-assisted laparoscopy in fertility-sparing surgery.

Women who will receive pelvic radiation for malignancy, such as lymphoma, cervical, anal, rectal, and urinary tract cancers, may benefit from ovarian transposition. Ovarian transposition aims to spare the ovaries from sterilizing doses of radiation by suspending them away from the radiation field. The utero-ovarian ligaments are transected, allowing the ovaries to be moved out of the pelvis and fixed to the abdominal wall peritoneum [71–73]. Either a high lateral suspension to the paracolic gutters or an anteromedial

suspension (3–4 cm above the umbilical line) may be performed, depending on the planned radiation field [71, 74]. When necessary, the proximal fallopian tube may also be transected to facilitate a high transposition. However, many surgeons prefer to leave the fallopian tubes intact whenever possible because spontaneous pregnancies may still be achieved [51, 71]. If patients should later need ART, transabdominal oocyte retrieval is an effective option for patients whose ovaries can no longer be accessed transvaginally [75].

Ovarian transposition is a relatively straightforward procedure, which can be performed by laparotomy or by laparoscopy. However, the laparoscopic approach conveys obvious advantages in terms of immediate recovery and healing. Standard laparoscopic oophoropexy requires endoscopic suturing or the use of endoscopic tacks to fix the ovary to the peritoneum. A robot-assisted approach may be used to facilitate the laparoscopic suturing needed for this procedure. Molpus and colleagues were the first to describe a case of robotic laparoscopic ovarian transposition in a 32-year-old woman requiring pelvic radiation for cervical cancer after radical hysterectomy and pelvic lymphadenectomy [76]. A key aspect to their approach was that they introduced the robotic laparoscope through a suprapubic trocar in order to facilitate visualization of the adnexa and upper pelvis. Their patient had significant pelvic adhesions following her prior surgery. Computer-assisted laparoscopic adhesiolysis, retroperitoneal dissection, and ureteral dissection allowed them to safely achieve a high lateral transposition in which the ovaries were suspended to the ipsilateral paracolic gutters without dividing the fallopian tubes. This case and others like it demonstrate that robotic ovarian transposition is feasible and would be an obvious choice when the robot is already in use for concurrent procedures and a high resuspension of the ovaries is required [76, 77]. As in the case presented by Molpus, robot-assistance may also prove advantageous when the need for retroperitoneal dissection or extensive adhesiolysis is encountered.

Computer-assisted laparoscopy may also find use in the key steps of ovarian tissue harvesting and transplantation for women undergoing ovarian

tissue cryopreservation. This experimental fertility-sparing technique involves the harvesting of whole ovaries, ovarian wedges, or strips of ovarian cortex for cryopreservation and eventual reimplantation and/or *in vitro* maturation and fertilization of oocytes [78]. Currently, ovarian tissue harvesting is one of the only fertility preservation methods available to prepubertal girls. It may also be useful for women who cannot undergo controlled ovarian hyperstimulation to bank oocytes or embryos prior to gonadotoxic chemotherapy and, unlike these ART options, adds the possibility to restore native ovarian endocrine function, as well as fertility.

Except in instances where laparotomy is necessary for other indications, ovarian tissue harvesting and reimplantation should be performed laparoscopically. The feasibility of laparoscopic ovarian tissue harvesting was well demonstrated by Oktay and colleagues, who harvested ovarian tissue from 52 women without conversion to laparotomy [79]. Mayerhofer and colleagues similarly retrieved ovarian tissue laparoscopically from 81 out of 85 women with no adverse events and concluded that laparoscopy should be the gold standard for the procedure [80].

When patients have been cleared by their oncologists to resume attempts at reproduction, strips of ovarian tissue can be thawed and reimplanted orthotopically (back to the ovary or ovarian fossa) or heterotopically (e.g., under the skin of the arm or the abdomen) [79]. For orthotopic transplantation, most prepare a transplant site on the recipient ovary by removing some of the existing ovarian cortex or by creating a tunnel beneath the cortex so that the tissue grafts can be sutured to decorticated ovarian medulla [79]. Alternatively, strips of preserved ovarian tissue can be sutured to a pocket created in the nearby peritoneum. Graft-site preparation and orthotopic transplantation can be accomplished by an advanced laparoscopic team, but most have resorted to an open approach [81, 82]. Additionally, those reporting laparoscopic variations of the procedure used oxygenated cellulose products as scaffolds to help secure the strips of tissue to the recipient ovary or peritoneum. It remains to be seen whether open or laparoscopic techniques result in better graft survival and function.

However, robotic assistance might resolve the potential difficulties of laparoscopic ovarian tissue transplantation without the need for technical compromises. One case study demonstrated that open techniques for orthotopic ovarian tissue transplantation could be faithfully replicated with robotic assistance [83]. In this example, the robotic surgical team successfully transplanted strips of thawed ovarian tissue on ovarian and peritoneal sites in a 38-year-old woman with ovarian failure following treatment for non-Hodgkin's lymphoma. The patient subsequently experienced return of ovarian function and relief of hot flashes within 6 months.

Ovarian graft function and longevity are generally temporary and appear to depend on ischemic injury and neovascularization. Whole ovary cryopreservation and transplantation have been proposed as a means to circumvent these issues. The concept of ovarian transplantation has been tested and proven in animal models and in a fresh human ovarian transplantation between monozygotic twin sisters [84–87]. In this method, an entire ovary is transplanted to an orthotopic or heterotopic recipient site by microsurgical vascular anastomosis. While no cases of laparoscopic or computer-assisted ovarian transplantation have yet been reported, robotic surgery has already been successfully applied to other procedures requiring vascular anastomoses, including renal transplantation and coronary artery bypass grafting [88, 89]. We thus foresee the possibility of applying this technology to ovarian transplantation in the future.

8.6 Conclusions

Reproductive endocrinology and infertility subspecialists must remain fully engaged in the management of patients seeking fertility preservation and enhancement of natural fecundity or ART success. Such engagement is incomplete when these highly trained providers relinquish their role as reproductive surgeons.

There is no doubt that assisted reproductive technologies and advanced laparoscopic techniques have transformed the role of surgery in the

practice of reproductive medicine. In particular, the development of advanced laparoscopy has set high technical standards in fertility-sparing and fertility-enhancing surgery. Laparotomy no longer has a role in reproductive surgery, with rare exceptions.

In fairness to all of us, we should recognize that a technological tsunami has overwhelmed our field in the course of the past generation, broadening our armamentarium to previously unimaginable levels. Reproductive specialists must remain focused to achieve excellence in their high-specialty field: there is no question that a great number of us have chosen to focus on assisted reproduction rather than surgery. Our review explains the possible reasons for the silent retreat of reproductive endocrinologists from the field of reproductive surgery and particularly from the discipline of laparoscopy, which had been synonymous with our field for good part of its early years [90]. We have covered in detail the many levels of ergonomic challenge implicit in laparoscopic surgery: from mechanical limitations due to the fulcrum effect, to musculoskeletal occupational injury, to safety concerns related to gaze disruption in the operating room. We have also highlighted how the retreat of many REI subspecialists from the front line of advanced laparoscopy has created a culture of disconnected care for infertility patients with surgically treatable conditions.

Computer-assisted laparoscopy, a readily available and accessible reality in most medical centers in the USA, represents a practical solution for reproductive endocrinology and infertility specialists to reclaim reproductive surgery as a high-specialty field. As demonstrated in the technical sections of this review, safety and non-inferiority studies of robotic surgery compared to conventional laparoscopic surgery are available for every type of reproductive surgery. The AAGL recently proposed that computer-assisted laparoscopy and conventional laparoscopy are to be seen as clinically equivalent [91]. At the same time, the association raises the question of price versus value when considering the higher direct costs of robotic technology compared to conventional laparoscopy. Some caveats come to mind,

however, when interpreting the current evidence related to costs introduced by a widespread utilization of computer-assisted surgery.

First, computer-assisted surgery is a practical ergonomical laparoscopic alternative to open surgery. Because of this, a meaningful cost analysis must consider all societal costs related to open surgery. These include cost related to complications of open surgery and cost of lost productivity of individuals removed from the workforce for extended periods of time. Elimination, or quasi-elimination, of open gynecologic surgery is something that conventional laparoscopy has failed to achieve in the course of an entire generation. Computer-assisted surgery has a realistic potential to change the demographics of surgery on a large scale and to therefore induce substantial savings for society. To date, a study of this scope has not been produced.

Second, the economics of robotic technology are expected to follow trends established by high-end electronic products in the same class—that is to say, a rapid upgrade of technology and an increased affordability over time. The recent AAGL Statement is based on evidence that has accumulated over the first 7 years of gynecologic surgery experience with one specific device whose concept and overall mechanics are over 10 years old. In contrast, those of us with a special interest in the field of surgical robotics can easily predict a different scenario, possibly just around the corner, in which diverse and more advanced robotic products will be competing in an exponentially receptive market. After all, we are merely witnessing the dawn of surgical robotics and computer-assisted laparoscopy. Current detractors of this technology appear to be shortsighted and risk to be eventually marginalized in their surgical profession by failing to recognize the start of a new surgical age. Reproductive endocrinology and infertility specialists in particular should be eager to take advantage of computer assistance to reclaim their place in the surgical arena as the champions of microsurgery, reconstructive surgery, and conservative surgery for all appropriate indications in women of reproductive age.

As highlighted in this review, reproductive surgeons are minimalists: they exercise restraint in

the operating room, strong in their deep knowledge of reproductive pathophysiology and in their extensive pharmacological and technological armamentarium. As such, they are likely to remain relatively low-volume, high-specialty operators. They need to provide focused, high-precision, minimally invasive surgical care to the select patients that truly need it. Computer-assisted surgery has the potential to shorten or eliminate learning curves for advanced laparoscopic operations and can maintain surgical skills through easily accessible integrated digital simulation. Therefore, its introduction in a relatively low-volume surgical practice makes even more sense. In terms of its potential to further advance the field of minimally invasive surgery, this rapidly developing technology will soon allow surgeons to bring multiple operative instruments in a patient's abdomen through a single incision that fits within the average umbilicus without the hyperbolic ergonomic challenges of standard single-site laparoscopy. Finally, a combination of computer-assisted laparoscopy and natural orifice transluminal endoscopy promises to provide an ultra-minimally invasive avenue to certain reproductive surgeries.

If REI subspecialists were awaiting a technological quantum leap to empower their leadership in high-specialty reproductive surgery, the time has now come. The obituary of open surgery for benign gynecology has been written, and computer-assisted laparoscopy meets our stringent surgical principles while overcoming the limitations of conventional laparoscopy. In spite, yet because, of the success of ART, the need for highly specialized operators has never been greater. It is only up to us to decide if, as reproductive endocrinologists, we want to be surgeons to our patients. As we say here in Boston: "Fish, or cut bait!"

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