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Videolaseroscopy

The CO₂ Laser for Advanced Operative Laparoscopy

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Advanced operative laparoscopy offers an appealing alternative to laparotomy for benign gynecologic disease. By eliminating a large abdominal incision, a laparoscopic surgical procedure generally requires short-stay hospitalization of less than 24 hours and allows full recovery in less than a week. Patients prefer laparoscopy intuitively because it is less painful and cosmetically acceptable; furthermore, patients perceive surgery done by laparoscopy as less invasive physically and less intrusive in their lives. Surgeons can visualize deep pelvic structures more easily and produce less de novo adhesions than with laparotomy,²⁸ preserving patients' future fertility. Health care costs are reduced, and workers return to full productivity rapidly.¹⁸ Thus, in the hands of a skilled, experienced operative laparoscopist, advanced operative laparoscopy is universally preferable to laparotomy for appropriately selected cases.

Our experience with video began in 1979, when the senior author (C.N.) devised a system that suspended a 2-pound video camera from the ceiling of a hospital animal laboratory and first inspected intra-abdominal organs with combined video monitor and laparoscope. We added the carbon dioxide (CO₂) laser to the operating channel of the laparoscope in the early 1980s with a fixed coupler, replacing the awkward joystick arrangement previously reported.⁴¹ Despite cumbersome equipment and vocal critics, an entirely new type of surgical intervention began to evolve. By a slow, empirical process, the additional new technology and the adaptation of standard surgical instruments for laparoscopic use have created a new surgical discipline, advanced operative laparoscopy. As described in the following, almost all benign pelvic disease can now be managed through a laparoscope.

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TRANSITION FROM LAPAROSCOPY TO ADVANCED OPERATIVE LAPAROSCOPY

Gynecologists have become familiar with the use of the laparoscope for simple, rapid procedures such as tubal ligation and diagnostic laparoscopy. When laparoscopy becomes surgical intervention, however, complicated, lengthy procedures are the result. It is therefore imperative that gynecologists understand the ways in which standard, familiar laparoscopic equipment has been adapted and new technology developed before beginning to learn advanced operative laparoscopy.

Videolaseroscopy (VLS), as the name implies, evolved by applying a video camera and then laser technology in operative laparoscopy. A video camera and color monitor system is required to perform VLS or any advanced operative laparoscopy. The monitor is placed at the eye level of the surgeon, enabling him or her to stand instead of stoop during long laparoscopic procedures. The image produced on the monitor is seen with binocular instead of monocular vision, allowing better depth perception. Magnification of about 6:1 is achieved with the combination of proximity of the scope to the tissues,³⁷ large color monitor image, and zoom function on the camera; this level of magnification is equivalent to that available with surgical loupes worn during microsurgery. Using a VHS video recording system attached to the monitor, a permanent record can be made of the condition of the pelvic organs and of the surgical outcome. Simultaneous audio commentary can be used to improve communication about the procedure with the patient or referring physician. Reviewing the video recording of the procedures is also an excellent self-teaching tool for the surgeon. The camera system is attached directly to the eyepiece of the laparoscope. Older, heavier cameras were generally designed for arthroscopy and cannot reproduce colors accurately enough to allow recognition of subtle pelvic disease such as endometriosis. In addition, because the weight attached to the eyepiece of the laparoscope can add to the cumbersome nature of the equipment, the camera should be as lightweight as possible (maximum 2 oz); available cameras weigh as little as 1.8 oz. High resolution of at least 375 lines is necessary to produce a bright, sharp image required for surgical manipulation; the charge-coupler device (CCD-3) type of silicon-chip camera provides the clearest image for VLS; this camera produces 420 lines of resolution and approaches, but does not equal, the resolution of the human eye, which will be achieved eventually with the state-of-the-art high definition camera, producing 1125 lines.³⁶ Thus, on rare occasions, the camera must be removed while the surgeon evaluates details through the eyepiece of the laparoscope.

The light source required to produce a clear image on the video monitor is more intense than those used previously for laparoscopy. A xenon light source provides the brightest lamp with the least color distortion. Halogen bulbs of 150 or 300 W can be used in conventional light sources and generally also provide enough light for most advanced operative laparoscopic procedures.³⁷ Because this intense light source produces more heat than conventional light sources, the surgeon must remain cautious of possible thermal damage to the bowel and of combustion of paper drapes.

The technique of VLS utilizes the CO₂ laser beam as a long knife. In this technique, the CO₂ laser beam is coupled directly to the operative channel of the laparoscope. We do not advocate use of fiber lasers and see no advantages to these over microelectrocautery. With this wavelength, the depth of thermal damage below the vaporized tissue is less than 0.5 mm.² Used at a high power setting (40–100 W) and especially used in the superpulse or ultrapulse (Coherent, Palo Alto, CA) mode, in which cycles of peak power are about five times the power output displayed on the panel, the CO₂ laser vaporizes tissue with precision; in this manner, the CO₂ laser can be used as a laparoscopic scalpel. Used at a low power setting (10–15 W) and in the continuous mode, more thermal damage and less vaporization occur, making the CO₂ laser also useful as a cautery. Coagulation of vessels smaller than 0.8 mm in diameter (roughly the diameter of the helium:neon [HeNe] beam) and contraction of the surface of overdistended hollow structures can be accomplished at this low power setting. Gynecologists are familiar with the concept of defocusing the handheld CO₂ laser beam by moving the beam back from the tissue to create a larger spot size and thereby a lower power density. In laparoscopy, however, the CO₂ laser focal length needs to be long enough to pass through the laparoscope channel before focusing. The spot size, therefore, remains almost constant at any distance from the tissue,¹⁷ and the beam cannot be defocused in the familiar manner. The power density can be reduced only by reducing the power setting or by defocusing the beam at the coupler end of the laparoscope by mechanically rotating the coupler.

The CO₂ laser beam is invisible, and therefore, an HeNe laser beam is emitted along the same path as the CO₂ laser beam, thus creating a visible CO₂ laser beam. In VLS, the HeNe beam must be at least 5 mW to remain visible on the video monitor because of the high-intensity light source.²⁶

In VLS, the CO₂ laser is coupled directly to the operating channel of the laparoscope, allowing cutting to occur only along the direct line of vision; the combined scope and laser unit thereby functions as a long scalpel in the dominant hand of the surgeon, without obstruction of vision. By grasping the suction-irrigation cannula in his or her other hand, the surgeon can then suction, irrigate, and apply traction in the surgical field. The CO₂ laser can be introduced into the abdomen in a separate puncture site instead, but this lacks the advantages described.

The disadvantage of the CO₂ laser is the production of intra-abdominal smoke. The plume of smoke decreases visibility in the surgical field and must be removed. To evacuate the smoke, a combined suction and irrigation cannula, the Nezhat-Dorsey suction-irrigator (NDSI; Karl Storz, Culver City, CA) has been developed. The cannula contains two separate channels for suction and irrigation, and each channel is activated by a trumpet valve at the top of the cannula, within easy access of the surgeon's hand. The suction channel is connected to wall suction; the suction contents initially enter a Vac-Rite (Becton Dickenson Acute Care) canister equipped with a laser plume filter, and all particles that might clog the wall suction are filtered out. When smoke is produced by laser vaporization of tissue, the suction valve is depressed by the surgeon, and the plume is rapidly

evacuated. Suctioning of large clots can also be accomplished by substituting a 10-mm cannula for the standard 5-mm device.

Because suctioning of smoke and fluids is necessary during VLS, pneumoperitoneum would be easily lost using a standard CO₂ insufflator. A high-flow system, activated only after intraperitoneal location has been confirmed by visualization, should therefore be used during VLS; 3 to 6 L/min of CO₂ can be delivered. Safety is maintained with a pressure monitor within the insufflator; gas flow automatically cuts off when abdominal pressure reaches a predetermined limit, generally 12 to 14 mm Hg.³⁷

Laser vaporization can produce char, and dissection can produce peritoneal debris. Using the same NDSI, the irrigation channel, controlled by a separate trumpet valve, can be triggered to wash char and debris from the surgical field. The irrigation channel is connected to 1 L of lactated Ringer's solution that is housed in a pump (Nezhat-Dorsey irrigation pump, Karl Storz, Culver City, CA). The pump is generally set at 200 to 300 mm Hg but can produce up to 800 mm Hg. Once irrigation has been accomplished, the suction channel is then used in rapid sequence to remove the fluid just introduced.

An additional use for the NDSI is as a backstop to the CO₂ laser beam. Gynecologists familiar with use of the CO₂ laser for cervical or vaginal disease are aware that when treating a solid structure, the laser penetrates the tissue beneath. In the abdomen, vaporization may be performed on a solid structure, such as the uterine fundus, but may also be required on a thin structure, such as an adhesion; once the beam has penetrated the tissue being vaporized, it begins to vaporize distant structures, such as blood vessels or organs, that may not be seen by the surgeon but that are in the direct path of the beam. Thus, a backstop placed directly behind the tissue to be vaporized limits the depth of penetration. The NDSI adapts easily to this purpose.

A technique known as *hydrodissection* has been developed to take advantage of the property of selective absorption of the CO₂ laser by fluid.²³ A layer of fluid injected under the surface of a tissue protects underlying tissues from laser vaporization, thus acting as an alternative backstop. The fluid continuously heats and evaporates, but the underlying tissues receive no energy. In hydrodissection, a 22-gauge needle is placed into an avascular area of the serosal surface or adhesion to be treated, and 20 to 30 mL of lactated Ringer's solution is injected. The CO₂ laser is then used to create a 5-mm opening in this fluid collection, and the tip of the NDSI is inserted into the opening. The trumpet of the irrigation channel is then compressed, and approximately 100 to 200 mL of additional fluid is injected subperitoneally, under pressure, which serves to dissect the peritoneum away from the vital organs beneath. The same technique, used at the junction of the round ligament to the pelvic wall, produces a fluid-filled broad ligament that can be safely vaporized on both the anterior and posterior surfaces.

Fiber lasers (argon, KTP 532, and Nd:YAG) can also be used in VLS, but are not as well adapted as the CO₂ laser. A fiber laser may be introduced through the operating channel of the laparoscope, but it obstructs visibility on the surgical field; therefore, the fiber is generally introduced through the central opening in the NDSI. KTP and argon are limited to low-power capability (12–14 W), at which point the fibers begin to melt. All fibers are

subject to breakage within the abdomen. Furthermore, energy from these lasers is absorbed well by tissue and can do thermal damage to the tissues surrounding the area intended to be treated; these lasers can, in fact, be considered expensive, technologically advanced forms of cautery. Finally, the surgeon's eyes, which are protected from CO₂ laser damage by the eyepiece of the laparoscope, require an appropriately tinted shutter to be placed over the eyepiece for each of the fiber lasers. The shutter distorts the color of tissues being treated by VLS.

Patient positioning is the last major consideration in adapting to advanced operative laparoscopy. Because a difficult advanced operative laparoscopic procedure can easily take 1 to 2 hours to complete, pressure points and strain on joints must be minimized. The patient is placed in a modified dorsal lithotomy position, with Trendelburg position and rotation added as needed to visualize internal structure. The legs are supported by padded Allen universal stirrups, which allow the knees and hips to remain at a minimum flexion to avoid nerve compression. Because the hips are flexed only slightly, the instruments in the suprapubic areas are not limited in range of motion. The arms are placed in foam troughs and tucked at the patient's sides; this provides padding of the antecubital space to protect the ulnar nerve and allows the surgeon and assistants to move freely around the patient, enabling them to better visualize the pelvis by positioning the laparoscope. To avoid compression of the vertebral spines, the patient's sacrum must rest on the table, but the buttocks must protrude off the table by a few centimeters to permit motion of the uterine manipulator.³⁷ The patient's eyes are covered with saline-moistened pads to protect them from CO₂ laser damage.

In summary, VLS differs from conventional operative laparoscopy and pelviscopy by use of a video camera and monitor system, high-intensity light source, CO₂ laser introduced through the scope, suction-irrigation cannula, hydrodissection, rapid-flow pneumoperitoneum insufflator, and lack of use of sutures. When beginning the transition from laparoscopy to advanced operative laparoscopy, the surgeon must become comfortable with this new armamentarium and only gradually increase the difficulty of surgical procedures undertaken. The addition of the camera to the endoscope has aided two important aspects of surgery: the role of the assistant has become clearer, and exposure and control of the field have become much easier.

OPERATING ROOM SETUP

Simplicity, reproducibility, and efficiency are the goals in organizing the operating room for VLS and advanced operative laparoscopy (Table 1). In simpler cases, one assistant stands on the patient's right, and the video monitor is placed at the patient's feet. In our operating room, two circulating nurses are available; one circulator is responsible for maintaining the NDSI and must constantly monitor fluid intake and output. The second circulator maintains the operation of the CO₂ insufflator, laser, light source, and cautery, and controls video recording of the procedure.

Our operating room arrangement is similar to that described by Dorsey elsewhere in this issue.

Table 1. Operating Room Setup

| |
|--|
| <i>Mayo stand 1*</i> |
| Dilatation and curettage equipment |
| Foley catheter |
| Cohn cannula |
| Hysteroscope |
| <i>Mayo stand 2</i> |
| Kleppinger bipolar forceps |
| Atraumatic forceps |
| Claw grasping forceps |
| Endoscopic scissors |
| <i>Back table</i> |
| Verres needle |
| Fiber-optic light cord |
| Allis and Kelly clamps |
| Scalpel |
| Connecting tubing for CO ₂ insufflator, suction, and irrigation |
| 10-mm operating laparoscope |
| 5-mm laparoscope |
| 10-mm sharp trocar |
| 3 5-mm sharp trocars |
| 10- and 5-mm rounded trocars (for reinsertion) |
| 18 and 22 gauge aspirating needles |
| 60-mL syringes |
| Vasopressin solution (20 U in 200 mL sterile water) |
| Indigo carmine (5 mL in 100 mL of lactated Ringer's solution) |
| Duplicate instruments, wrapped |
| Endoloops with applicator |
| Endoclip applicator |

*Remains sterile in the event that uterine manipulator needs to be repositioned.

OPERATIVE PROCEDURE

In its simplest form, VLS requires a laparoscope and a minimum of two suprapubic portals. Initial patient evaluation, including examination under anesthesia, dilatation and curettage, and videohysteroscopy, is performed. A Foley catheter is inserted and continuous drainage is begun, both to minimize the chance of injury to the bladder during trocar insertion and to provide easy urinary output measurement when large quantities of irrigation are introduced. A Cohn cannula uterine manipulator is inserted into the uterus, and vaginal instruments are kept sterile, should the manipulator need replacement later in the case.

An 11-mm trocar is inserted at the umbilicus, and the laparoscope is inserted. All other trocars are then inserted under direct visualization. The left and right suprapubic 5-mm trocars are placed at the pubic hairline, about 4 cm from the midline; the NDSI is inserted on the patient's left. Atraumatic and claw grasping forceps, aspiration needles, bipolar Kleppinger forceps, endoloop sutures, and endoclip applicators can be introduced, as needed, into the right portal. If necessary, a third, midline trocar can be placed 1 to 2 cm more cephalad than the other trocars, anticipating the location of the dome of the bladder.

All types of VLS and advanced operative laparoscopic procedures are accomplished with the same general surgical approach. The surgeon manip-

ulates the laparoscope-CO₂ laser-camera unit with the dominant hand and the NDSI with the other hand. The NDSI is used initially to manipulate tissue and achieve surgical exposure. The surgical assistants are handed tissue that has been grasped by the surgeon, and they provide traction and countertraction by placing the uterus on stretch and elevating the pedicles of tissue.

It is crucial that only the surgeon fire the CO₂ laser and that the HeNe beam is visible before firing to ensure that no tissue or organ is trapped at the outlet of the laser channel. If the beam is not visualized after moving the laparoscope within the abdomen, the scope must be withdrawn and the presence of the HeNe beam reconfirmed. When the beam does not appear despite adequate laser function and proper coupler attachment, the operating channel of the laparoscope must be suctioned from the bottom or irrigated from the top. Finally, the CO₂ insufflation tubing must be attached at the top of the operating channel, rather than the trocar sleeve, keeping the channel clear during the procedure.

Instruments specifically developed or adapted to endoscopic surgery will become more prevalent in the near future. Endoloop sutures (preformed slipknots attached to a rigid, disposable applicator) are available in chromic, polyglactin, and polydioxanone (Ethicon, Somerville, NJ). These sutures are placed above the pedicle to be ligated; the pedicle is then grasped through the suture loop by a forceps introduced on the contralateral side of the abdomen. The loop is tightened, and the suture is cut with the laser against a backstop or with scissors. A new endoclip applicator, similar to the gastrointestinal endoclip applicator (Ethicon, Somerville, NJ) used in intestinal surgery, is being developed; this instrument, which is introduced into the abdomen through a 12-mm suprapubic trocar, places six rows of small titanium clips and simultaneously cuts the pedicle along the center, leaving three rows of clips on each side of the pedicle. The tissue to be clipped and cut is placed on stretch with a grasping forceps, and the jaws of the endoclip applicator are placed exactly where the incision is desired.

Tissue removed during advanced operative laparoscopy is generally withdrawn from the abdomen through one of the suprapubic portals. When tissues such as a myoma or adnexal mass prove too large to fit through the 5-mm trocar, several alternatives are available, using equipment stored on the back table:

1. A long grasping forceps can be introduced into the operating channel of the laparoscope. The tissue to be removed from the abdomen is grasped, and the tissue and laparoscope are withdrawn simultaneously through the 10-mm sleeve.

2. A 10-mm trocar can be inserted in place of one of the 5-mm suprapubic trocars, allowing a 10-mm morcellator or claw-tooth grasping forceps to be introduced. Because endometriosis or metastatic tumor can occur at the site of laparoscopic trocar insertions,^{12, 19} it is best to deliver tissue all the way into the trocar sleeve without touching the tissue to the abdominal wall and then to remove the trocar, forceps, and tissue as a unit.

3. A colpotomy incision can be made from above by aiming the CO₂ laser at an instrument or sponge within the vagina, entering the posterior

fornix; a standard vaginal colpotomy could also be performed. The tissue is then grasped from below and removed vaginally.

4. One of the suprapubic punctures can be extended to a 2-cm minilaparotomy incision, through which the tissue can be grasped and removed. This technique can also be used in laparoscopically assisted minilaparotomy, in which a tube or ovary to be repaired or removed is located laparoscopically and then delivered onto the anterior abdominal wall with atraumatic forceps.

Signs stating "Video recording in progress" or "Laser in use" should be posted on the door in any such cases. Initially video recording can be accomplished when inspection has been completed and before surgical intervention is begun. At the appropriate time in the procedure, the CO₂ laser is coupled to the operating channel of the laparoscope by the circulator. Because the procedure is considered to be clean but not sterile, draping the laser arm is unnecessary. The video camera, which is cleaned with alcohol but never sterilized by gas,¹⁴ can be draped in a disposable plastic bag. Once the HeNe beam can be seen exiting the distal end of the laparoscope, it is test fired onto a wet tongue blade to ensure alignment of the CO₂ laser and HeNe beams. After the CO₂ laser beam is inside the peritoneal cavity, safety glasses are no longer mandatory for operating room personnel.

PREOPERATIVE CONSIDERATIONS

Relative Contraindications

Severe cardiovascular disease, large abdominal or diaphragmatic hernia, complete bowel obstruction, advanced pregnancy, and large intra-abdominal mass extending above the umbilicus can all be considered relative contraindications to advanced operative laparoscopy. Preoperative suspicion of ovarian cancer should preclude laparoscopic approach. Finally, proper case selection based on the experience of the surgeon is crucial.

Patients with Previous Laparotomy

Whereas direct trocar insertion without prior pneumoperitoneum has been advocated as safer,³² this technique should not be applied to patients with previous laparotomy. Many candidates for advanced operative laparoscopy have had previous gynecologic procedures performed by laparotomy, and establishing a pneumoperitoneum in these patients requires additional caution. One technique is to explore the periumbilical area where Verres needle insertion is planned by inserting a 18-gauge spinal needle first, attempting aspiration. Should blood or fecal material return, this area is abandoned and a lateral area is tested in the same manner. When an acceptable area has been identified, a 5-mm laparoscope is inserted to allow full inspection for intestinal or omental adhesions before the 10-mm scope is finally introduced. Other methods of examining the abdominal cavity before trocar insertion are described by Dorsey elsewhere in this issue.

Possible Bowel Lesions

Patients with previous laparoscopically noted bowel adhesions, multiple previous laparotomies, bowel symptoms, or cul-de-sac nodularity should

undergo bowel preparation before laparoscopy. The following protocol has been useful:

1. Clear liquids 1 day before surgery; nothing by mouth after midnight.
2. GoLYTELY, 1 gallon orally; begin drinking at 6 PM 1 day before surgery. Should the patient refuse GoLYTELY, the following steps may be substituted:
 - a. Magnesium citrate, 300 mL at 6 PM 1 day before surgery.
 - b. Fleet enemas at 4 PM and 8 PM 1 day before surgery.
3. Metronidazole, 1 g orally at 11 PM 1 day before surgery.
4. Cefoxitin, 2 g intravenously 30 minutes before procedure.

The surgeon must be aware that distended loops of bowel can occasionally result from this protocol, adding to the difficulty of the procedure.

ANESTHESIA CONSIDERATIONS

Postoperative nausea is probably the most common problem in advanced operative laparoscopy, possibly because of CO₂ conversion to carbonic acid at peritoneal surfaces. Preoperative management using a combination of transdermal scopolamine and droperidol appears to be an effective regimen.¹ A new induction anesthetic, propofol, which possesses a short half-life suited to outpatient procedures, also has antiemetic properties.⁸ Intravenous metoclopramide can be added if nausea occurs in the recovery room. Postoperative analgesia is necessary, but narcotics can contribute to nausea. A new parenteral analgesic, ketorolac, offers a nonsteroidal anti-inflammatory alternative.³⁴ Additionally, there is less risk of respiratory depression after dismissal from the hospital, when narcotics are avoided.

Controlled ventilation under general endotracheal anesthesia offers the most effective management for patients undergoing VLS and advanced operative laparoscopy. Intraoperatively, the use of the Trendelenburg position, CO₂ insufflation, and copious irrigation with lactated Ringer's solution combine to add weight against the diaphragm, compromising diaphragmatic excursion. Furthermore, CO₂ insufflation can raise the patient's PCO₂, producing respiratory acidosis¹¹; the end tidal CO₂ can be measured and counteracted with increased respiratory rate when necessary. Finally, better abdominal muscle relaxation can be achieved with general anesthesia. Standard induction, narcotic management, and cardiovascular monitoring, including single-lead electrocardiography, continuous blood pressure monitoring, pulse oximetry, esophageal stethoscopy with thermometer, nerve stimulation, on-line CO₂ analysis, and mass spectrometry with capnographic capabilities, are applicable (K. D. Smith, MD, personal communication).

Regional anesthesia can also be applied in advanced operative laparoscopy if necessary. Good results have been reported using epidural anesthesia.³ Rectus sheath block is another available technique.³⁸

During VLS, intake and output of fluids require meticulous monitoring.

Initial hysteroscopy introduces uterine-distending media into the peritoneal cavity. During laparoscopy, as much as 20 L of irrigation fluid can be instilled. By gradually mobilizing this fluid, otherwise healthy young women can develop pulmonary edema in the recovery room. A recently developed device, the BoMed Medicals and Manufacturers noninvasive cardiac output monitor, provides data comparable to those with a Swan-Ganz catheter while operating with electrocardiograph-like surface electrodes.³⁹ The trans-thoracic fluid capacity reading appears to be the most useful parameter, assisting the anesthesiologist in determining whether to administer a diuretic. A large discrepancy (>1000 mL) in intake and output is an indication to treat with furosemide.

Dysrhythmias including junctional rhythm, bradycardia, bigeminy, and asystole have been associated with CO₂ insufflation of the abdomen. Bradycardia appears to result from pressure on the peritoneum with increased vagal response.¹⁶ Intravenous glycopyrrolate, which has vagolytic effects, can be given preoperatively, and atropine must always be available.

CO₂ embolism is a possible but rare complication⁷; if it is suspected, the patient should be hyperventilated with 100% oxygen, and cardiovascular support should be maintained. If a central line is present, an attempt should be made to aspirate the embolus.

Postoperatively, patients remain in the recovery room for a minimum of 1 hour and are not dismissed until alert and oriented. Frequently, patients are transferred to a short-stay unit for additional observation.

SPECIFIC APPLICATIONS

Endometriosis

Because the CO₂ laser beam can easily vaporize areas of endometriosis, this disease was an initial logical application of VLS. After years of experience, VLS has been proved to be at least as effective as laparotomy for restoration of fertility in stage I and II endometriosis (American Fertility Society classification) and superior in treatment of stage III and IV²¹ and prevention of postoperative de novo adhesions.²⁸ Pain relief after VLS in patients with endometriosis has also been effective.³¹ The treatment of endometriosis is described by Martin elsewhere in this volume.

We have written an article dealing exclusively with endoscopic management of endometriosis,⁴³ which also presents the first laparoscopic rectal wall resection and reanastomosis for deeply infiltrative endometriosis.⁴⁷ Also, the first laparoscopic ureteral resection and uretero-neocystostomy for endometriosis of the ureter is presented.⁴⁸

Tubal Adhesions and Hydrosalpinx

Vaporization of peritubal adhesions by VLS has proved effective in preserving fertility if the anatomy of the lumen, including major and minor folds of the mucosa and cilia, has not been destroyed by disease.^{20, 30} Fimbrioscapy,³³ a method of further evaluating the tubal anatomy intra-operatively, is accomplished by suspending the fimbria in fluid. The

posterior cul-de-sac is filled with lactated Ringer's solution, and a 3-mm laparoscope with video camera attached is introduced by one of the suprapubic portals. The smaller scope can magnify folds of the fimbria with closeup images, and agglutination or adhesions can be readily identified and then incised with the laser.

Prognosis for pregnancy when tubal anatomy has been destroyed is poor.^{20, 30} Although an attempt should be made to repair even these tubes during VLS, these patients may eventually become candidates for in vitro fertilization. Exposure of ovaries for subsequent ovum retrieval by future laparoscopy or ultrasound aspiration must therefore become as important as tubal repair in these cases. Ovarian adhesiolysis is carried out using VLS techniques described earlier.

If a hydrosalpinx is encountered, results of repair by advanced operative laparoscopy are comparable to those achieved with microsurgical laparotomy repair.^{13, 20} The distal end of the tube should be distended with indigo carmine chromotubation and stabilized with two grasping forceps. Stellate incisions are made in the end of the tube using high-power laser, while all remaining fimbria are carefully preserved. The edges of the neosalpingostomy must be everted to preserve tubal patency; a low-power laser beam applied circumferentially to the distal serosal surface causes serosal contraction and eversion of the mucosa. Sutures should be avoided, to reduce adhesion formation.

Ectopic Pregnancy

An increased incidence of ectopic pregnancy, combined with rapid serum human chorionic gonadotropic assays and high-resolution vaginal ultrasounds, make management of unruptured ectopic pregnancy a procedure that the operative laparoscopist is likely to encounter. New medical management techniques using ultrasound-guided injection of methotrexate, potassium, or prostaglandin F₂ α may someday replace primary laparoscopic management of ectopic pregnancy; selection protocols for medical versus surgical management are not considered here.

When laparoscopy is used to confirm the presence of an unruptured tubal pregnancy, surgical management should be instituted at that procedure. The patient's desire for preservation of fertility and history of previous ectopic pregnancies should, of course, be clear to the surgeon preoperatively. The patient must understand that salpingectomy may become necessary despite her preference and that laparotomy may have to be performed. Ectopic pregnancies of any size or location can be managed laparoscopically by an experienced endoscopic surgeon.²⁴ Finally, the need for careful follow-up after conservative management must be explained to the patient.

In patients who desire permanent sterilization, coagulation using bipolar Kleppinger forceps over a small ectopic pregnancy both destroys the tubal pregnancy and produces sterilization.⁹ In larger ectopic pregnancies (>6 cm), or in cases of spontaneous tubal rupture or more than one recurrent ipsilateral ectopic pregnancy, salpingectomy may be the more prudent procedure. Salpingectomy is accomplished by placing the fallopian tube under traction using grasping forceps, serially coagulating with bipolar

cautery, and cutting with high-power laser beam the isthmus and mesosalpinx. The GI-A type of endoclip applicator will become an attractive alternative for salpingectomy; the applicator is placed along the mesosalpinx, parallel to the fallopian tube, and is triggered, simultaneously clamping and cutting the pedicle.

Salpingotomy has been shown to produce higher subsequent pregnancy rates and lower recurrence rates of ectopic pregnancy than has salpingectomy.⁴⁰ Linear salpingotomy should be attempted in patients who wish to preserve the affected tube and who are hemodynamically stable. Dilute vasopressin is injected into the mesosalpinx using a 22-gauge aspirating needle inserted through a 5-mm portal or using a 22-gauge spinal needle inserted directly through the abdominal wall; direct vascular injection of vasopressin must be avoided. The fallopian tube is grasped and extended, and a 1.5-cm linear incision is made along the antemesenteric surface of the tube. The products of conception are allowed to extrude through the newly created salpingotomy or are flushed out using the NDSI inserted into the tubal opening then grasped and removed from the abdomen. Copious irrigation within the tube and the pelvis ensures removal of the tissue and adequate hemostasis. Chromotubation with indigo carmine can provide information about tubal patency and also can flush the remaining products from the tube. Vigorously grasping tissue that remains adherent to the mucosa can cause hemorrhage and must be avoided. Human chorionic gonadotropin levels must be measured weekly until they are below 15% of the initial preoperative value. Plateauing or rising levels require further medical or surgical management.

Segmental resection of the tube has a better prognosis in the narrow isthmus portion of the tube, possibly because pregnancies in this site tend to infiltrate deeper into tubal tissue layers and are smaller and therefore less well defined for surgical manipulation.⁵ Segmental resection may also be used in cases of persistent tubal pregnancies. The segment to be excised is coagulated at each end using bipolar cautery or sterilization clips and is transected using the laser. The mesosalpinx of the segment is then cauterized and incised. As much fallopian tube as possible should be preserved so that reanastomosis with microsurgical technique can be accomplished at a later date.

Aspiration of large amounts of blood clots can be accomplished by substituting a 10-mm cannula on the NDSI. If active bleeding is not rapidly controlled, however, laparotomy should be instituted without delay.

Adnexal Mass

Before discussing laparoscopic management of adnexal masses, the risk of malignancy must be considered. In selecting cases, a strong suspicion of cancer based on clinical presentation, presence of ascites, advanced age of patient, strong family history, or patient history of cancer should preclude a laparoscopic approach. Two large laparoscopic series have demonstrated that the incidence of malignancy in patients with known pelvic mass is low: 1.2%¹⁶ and 0.4%²⁷; size of mass and complex or solid ultrasonic appearance were not considered indications for exclusion in these series, because common benign conditions such as myomata and benign cystic teratomas

would have been excluded. Furthermore, re-evaluation of intraoperative spillage at laparotomy has demonstrated no adverse effect on the prognosis of stage I ovarian cancer.⁶ What must be considered, therefore, is whether the benefits of avoiding laparotomy in 99% of women with pelvic masses outweigh the risk of inadvertently manipulating malignancy. The surgeon must make a decision on a case-by-case basis, considering the individual patient's wishes; the patient must be informed that advanced operative laparoscopy is not yet the standard of care for adnexal masses, that cancer can be encountered, and that subsequent laparotomy may be necessary. Finally, management of even the most benign-appearing mass must follow a protocol that obtains pelvic and cyst fluid cytology and that removes the mass for histologic examination; simply aspirating a cyst or vaporizing the capsule is not an acceptable alternative. By following this protocol, earlier, smaller cancers may actually be discovered because surgeons will be less reluctant to perform laparoscopy than to perform laparotomy for a small mass, and no malignancy will be overlooked.

In approaching a simple ovarian cyst, the cyst is first aspirated and drained through an 18-gauge aspiration needle inserted through the central channel of the NDSI or through one of the other suprapubic portals. Use of the NDSI system has the advantage of reducing spillage by applying suction at the cannula as well as the needle, thereby stabilizing the cyst. Fluid thus obtained is sent for cytologic analysis, and the cyst is mobilized by lysis of adhesions to the lateral pelvic wall, uterus, or bowel. Copious irrigation of the cyst and pelvis is then indicated, especially in cases of benign cystic teratoma, mucinous cystadenoma, or endometrioma. The most dependent portion of the cyst wall is opened further, and the internal surface is inspected. Dilute vasopressin is injected between the capsule and ovarian cortex to create a plane of hydrodissection and to reduce oozing in the capsule bed. The capsule is then stripped from the ovarian stroma using two grasping forceps, or excised using the laser, and is submitted for pathologic examination. The laser can then be used at low power to seal blood vessels at the base of the capsule and at higher power to vaporize small remnants of capsule. Cases involving large cysts may require partial oophorectomy, using a high-power laser, to remove the portion of the ovary distorted by the cyst. The defect in the ovary is left to heal without suturing. If the edges of the ovarian capsule do not spontaneously approximate, a low-power laser beam can be used to invert them by treating the inner surface of the defect, causing the surface so treated to contract and invert.

If salpingo-oophorectomy is indicated, the infundibulopelvic ligament is cauterized incrementally with bipolar cautery and incised with laser. If oophorectomy is chosen, the meso-ovarium is cauterized similarly and incised with a laser, or endoloop ligatures can be placed at the base of the pedicle, which is then incised. The gastrointestinal endoclip applicator will become a valuable alternative for oophorectomy in the near future by simultaneously clamping and incising the pedicle. The endoloop could be applied to the infundibulopelvic ligament instead of bipolar cautery or gastrointestinal endoclip applicator, but the risk of adhesion formation is increased. Removal of the ovary from the abdomen must then be accomplished through one of the trocar portals, by colpotomy, or through a minilaparotomy incision (see earlier section on the operative procedure).

Peritubal cysts can be removed in patients who desire preservation of the fallopian tube. Lactated Ringer's solution is injected between the capsule of the cyst and the mesosalpinx (hydrodissection), the cyst is incised with a laser, and the capsule is grasped with forceps. The NDSI is used to shell out the capsule, and hemostasis is achieved with a low-power laser or cauterly. The edges of the mesosalpinx are left to heal secondarily.

Ovarian remnant syndrome, a complex surgical problem, can be managed with VLS. Adhesions are lysed using high-power laser and proper backstop. The peritoneum is grasped along the lateral pelvic wall, in the area of the infundibulopelvic ligament, and a small opening is created with the laser. The NDSI is inserted, and hydrodissection is used to create a plane in the retroperitoneal space. The course of the ureter is delineated, and the ovarian remnant is gradually dissected free. The ovarian vessels are either coagulated or ligated with endoloop sutures, and then incised with a high-power laser; a gastrointestinal endoclip applicator could be used in this instance as well.

Disease of the Uterine Fundus

Adenomyosis remains a diagnosis of exclusion and is without effective treatment, unless hysterectomy is performed. The Nd:YAG laser is able to penetrate deeply and coagulate large volumes of tissue,²⁵ characteristics that are theoretically useful in treating adenomyosis. A preliminary study was therefore conducted in a small series of women presenting with dysmenorrhea and menorrhagia who had other causes excluded by hysteroscopy and laparoscopy and who did not desire future fertility. Relief was achieved in 75% of patients.²⁵ A green-tinted filter and goggles are added to the operating room setup. A bare Nd:YAG fiber laser set at 50 W is repeatedly inserted 1 to 1.5 cm into the myometrium at 15 to 25 randomly selected sites for 3 to 10 seconds each. The myometrium is approached from both the serosal and endometrial surfaces; the fiber is inserted through the hysteroscopy in the endometrial approach, but constant laparoscopic surveillance is maintained to be sure perforation or fiber contact with adjacent structure does not occur.

Laparoscopic myomectomy initially appeared to offer the same advantages as other advanced operative laparoscopic procedures. In practice, however, myomectomy should probably be managed by microsurgical laparotomy in patients desiring future fertility. Removal of large, symptomatic intramural myomata produces large defects in the myometrium, which can only be approximated coarsely using large-caliber sutures during laparoscopy; a large number of thick adhesions have been noted on follow-up (F. Nezhat, MD, and C. Nezhat, MD, *Int J Fertil*, in press). Small (<5 cm) or pedunculated myomata can be removed with fewer adhesions resulting, but these are generally incidentally discovered lesions, where myomectomy otherwise might not be indicated. Because patients who are aware of the advantages of advanced operative laparoscopy may insist on laparoscopic myomectomy, they must be made aware that the risks of blood loss and possible hysterectomy remain whether the procedure is managed by laparoscopy or laparotomy and that the laparoscopic approach may be detrimental to future fertility.

Patients with indications for laparoscopic myomectomy are managed with gonadotropin-releasing hormone analogues for up to 3 months preoperatively. Reducing tumor size, improving operative handling, and reducing intraoperative blood loss are theoretical advantages that could not be documented, but three months of amenorrhea does improve preoperative hematocrits. Patients are also given the option of autologous blood donation.

The surgical procedure of laparoscopic myomectomy can be viewed as two stages. Removal of the tumor from the uterus is generally straightforward, whereas removal of the tumor from the abdomen is long and tedious. A pedunculated myoma is simply excised at the stalk using high-power laser, and bleeding is controlled with bipolar cautery. For intramural or subserosal myomata, 5 to 10 mL of dilute vasopressin is injected under the capsule. The capsule is then incised with a high-power laser and gradually dissected away using a combination of grasping forceps, NDSI, and laser. Traction on the myoma can be produced with a small hook or a claw forceps. Once the myoma is removed, the base is thoroughly irrigated, and hemostasis generally requires bipolar cautery rather than low-power laser. Whether to suture the myometrial defect closed remains up to the judgment of the surgeon; if suturing is necessary, 4-0 polydioxanone (Ethicon, Somerville, NJ) endosutures are probably best applied. Intraligamentous myomata are approached by incising the anterior leaf of the broad ligament with laser after identifying the location of large vessels, ureter, and bladder. Excision is then accomplished as described for subserosal myomata.

The excised myoma can be removed from the abdomen by morcellation using scissors (laser is unnecessary in this instance because hemostasis is no longer a factor) until the fragments are small enough to fit through the 10-mm suprapubic portal. If morcellation is technically impossible, a colpotomy or minilaparotomy incision is made. Postoperative ecchymosis of the abdominal wall can result.

Hysterectomy (Laparoscopically Assisted Vaginal Hysterectomy)

Most gynecologists agree that patients undergoing vaginal hysterectomies experience less postoperative pain and require a shorter period of recuperation than do patients undergoing abdominal hysterectomies. Most hysterectomies, however, are abdominal hysterectomies, performed because of suspected concomitant pelvic disease, such as adhesions, endometriosis, or myomata. Operative laparoscopic hysterectomy or assisted vaginal hysterectomy has been used to provide more patients with an alternative to abdominal hysterectomy. Preliminary results confirm less intraoperative blood loss and shorter recuperation, without increased risk of complications.²²

Laparoscopic inspection and management, including lysis of adhesions, treatment of endometriosis, and salpingo-oophorectomy when indicated, are accomplished exactly as described for VLS. The uterus may then be removed by standard vaginal hysterectomy technique, retaining the laparoscope for later inspection of the surgical site, or the procedure may be continued laparoscopically.

Initially, we used bipolar cautery for coagulation of pedicles and scissors or CO₂ laser for transection.²² The infundibulopelvic ligament (or utero-

ovarian ligament, if adnexa is to be retained) and the round ligament are cauterized and incised. Hydrodissection is used to create a bladder flap, which is then incised with laser. The broad ligament is cauterized and incised anteriorly and posteriorly. The uterine vessels are identified, skeletonized, cauterized, and divided. A ring forceps is placed into the vagina, allowing first posterior and then anterior colpotomy incisions to be accomplished with the laser. The uterosacral ligaments are then approached vaginally, clamped, and incised; the uterus is removed; and the peritoneum is closed using standard vaginal hysterectomy technique, while simultaneous inspection through the laparoscope ensures that no organs prolapse during closure.

Laparoscopically assisted vaginal hysterectomy has been accomplished more easily using a prototype gastrointestinal endoclip applicator.²⁹ A 12-mm midline suprapubic trocar allows the clip applicator to be introduced. The infundibulopelvic, round, and broad ligaments are each clamped and incised simultaneously, with excellent hemostasis. Uterine arteries were triply clamped with large, individual titanium clips, placed at right angles to the artery, and transected with a high-power laser, leaving two clips laterally and one on the specimen. The remainder of the hysterectomy is completed as described earlier, including laser colpotomy incisions and vaginal completion of the procedure.

We have performed a radical hysterectomy para-aortic, and pelvic node dissection in a patient with cancer of the cervix with good results.^{29, 44, 45}

APPLICATIONS OF ADVANCED OPERATIVE LAPAROSCOPY IN GYNECOLOGIC ONCOLOGY

Laparoscopic radical hysterectomy has been accomplished by us in one case. This procedure was performed with the help and at the suggestion of the patient's gynecologic oncologist. The patient was thin and had microinvasive cervical carcinoma. Precise visualization of deep retroperitoneal pelvic spaces helped compensate for the loss of the ability to palpate. Hydrodissection was used to delineate the anatomy of the paravesicle, pararectal, paravaginal, and rectovaginal spaces, vesicovaginal; vascular pedicles were clipped or cauterized then incised with a high-power laser. The para-aortic, common iliac, external iliac, and obturator spaces were easily exposed, allowing node dissection. Laser colpotomy incisions then allowed en bloc vaginal removal of the specimen.

Some authors suggest laparoscopic staging of ovarian carcinoma before debulking the tumor at laparotomy.^{4, 35} Although pelvic washings for cytology, biopsies, omentectomy, and inspection of the undersurface of the diaphragm can all be accomplished by laparoscopy, management of ovarian cancer remains the one area of gynecology in which laparotomy is clearly preferable. During second-look follow-up surgery, however, laparoscopy has been used to sample small areas of peritoneum and para-aortic nodes. The peritoneum overlying the sacral promontory is entered using hydro-

dissection, and para-aortic node sampling can be accomplished at the level of aortic bifurcation.

Presacral Neurectomy

Presacral neurectomy can be useful in patients with central pain and dysmenorrhea due to endometriosis.⁴² The technique is essentially the same as para-aortic node sampling, except that the presacral nerve bundle is identified and 2 to 3 cm of it is removed.

Appendectomy

The appendix can be removed by advanced operative laparoscopy at the time of appropriate gynecologic procedures or when appendicitis is suspected. Prophylactic antibiotics are suggested. Lysis of periappendiceal and pericecal adhesions is accomplished by VLS techniques, allowing the distal appendix to be grasped. Bipolar coagulation or endocoagulation of the mesoappendix must be carried out above the cecum, allowing a margin of viable tissue at the appendiceal-cecal junction. The cauterized area is incised with a high-power laser, and a chromic endoloop suture is passed through a suprapubic portal, applied at the base of the appendix (5 mm from the cecum), tied securely using the applicator, and cut. A second endoloop suture is applied over the first, and a third is placed 5 to 10 mm distally on the appendix to close off the lumen and held for later specimen retrieval. The appendix is then transected between the second and third sutures, and the stump is sterilized by superficial vaporization with the laser and generously irrigated. The appendix is removed from the abdominal cavity by introducing a grasping forceps through the operating channel of the laparoscope and removing appendix, forceps, and scope as a unit, or it is removed through a 10-mm suprapubic trocar. Postoperative management differs from other advanced operative laparoscopic procedures only in that patients are to avoid solid food for 24 hours.⁴⁶

COMPLICATIONS

Advanced operative laparoscopy, as all surgical procedures, carries associated risks. Complications associated with insertion of the trocars or establishment of pneumoperitoneum are identical to those known in standard laparoscopy. Direct trocar insertion in patients without a history of laparotomy has reduced the incidence of mediastinal and omental emphysema by insufflating only under direct visualization. Vascular injuries remain possible, however.

During advanced operative laparoscopy, insertion of numerous ancillary trocars increases the likelihood of inferior epigastric vessel injuries. Transillumination of the abdominal wall and careful selection of peritoneal sites by direct inspection can reduce but not eliminate these injuries, because branches of these vessels are located within the rectus muscle layer. Bipolar cautery can control this bleeding, but expanding the suprapubic incisions by 1 to 2 cm may occasionally be necessary to gain access to and suture the vessels.

Fluid overload due to hydrodissection and copious irrigation should be avoided by accurate input and output tallies (see section on anesthesia considerations). Hydrodissection can also produce transient edema of the external genitalia, which requires only expectant management.

Specific intraoperative injuries to uterus, intestine, bladder, and ureter have been reported; identifying anatomy clearly before laser vaporization is imperative. Laceration of pelvic vessels during laser vaporization must be rapidly controlled. A 10-mm suction cannula should be used, enabling the surgeon to clearly identify, grasp, and cauterize the pumping vessel with bipolar Kleppinger forceps. Laparotomy becomes necessary if the vessel is not promptly isolated, if expanding retroperitoneal hematoma occurs, or if a major vessel is traumatized.

In experience with close to 5000 subsequent cases of VLS, serious complications have been extremely rare. One postoperative acute abdomen occurred in a patient who proved to have congenital malrotation of the mesentery on exploratory laparotomy. Five cases of postoperative bleeding required a second procedure; all were due to abdominal wall vessel injury. Wound infection, postoperative fever, and urinary retention have been the more common postoperative problems and are managed by a standard medical approach.

CONCLUSION

Endoscopic surgery has forever changed the field of gynecology and general surgery. Because of patient convenience and cost-effectiveness, advanced operative laparoscopy should be offered in any condition in which it is at least as efficacious as laparotomy. As more surgeons become skilled in advanced operative laparoscopy, it is possible to predict that in the not too distant future, laparotomy will be contraindicated for the treatment of benign pelvic disease in women of reproductive age.

VLS was developed slowly over a decade, with new skills added after easier procedures were mastered. For the past 3 or 4 years, we have been avoiding up to 98% of laparotomies for the management of benign pelvic disorders. Each surgeon attempting advanced operative laparoscopy must approach this discipline in the same systematic way, keeping patient safety the highest concern. Mastering the new high-technology surgery will ultimately benefit patients, surgeons, and society.

REFERENCES

1. Baily PL, Bubbers SJ, East KA, et al: Transdermal scopolamine reduces postoperative nausea and vomiting. *Anesthesiology* 69:A 641, 1988
2. Bellina JH, Bandieromonte G: Principles and Practices of Gynecologic Laser Surgery. New York, Plenum Medical Book Co, 1984, p 81
3. Bridenbaugh LD: Regional anesthesia for outpatient surgery. *Can Anaesth Soc J* 30:548, 1983
4. Dagnin G, Marin G, Cladiron MW, et al: Laparoscopy in staging, follow-up and restaging of ovarian cancer. *Gastrointest Endosc* 33:81, 1987