Tissue extraction techniques for leiomyomas and uteri during minimally invasive surgery have been performed for decades, but recent years have seen a vast expansion of techniques to address risks associated with tissue dispersion. Use of power, or electromechanical, morcellation has largely been replaced by manual morcellation with a scalpel. Morcellation can take place through a laparoscopic incision, a minilaparotomy incision, or through a colpotomy. Containment systems are now available for both power and manual morcellation, allowing tissue fragmentation to take place within an enclosed specimen bag. These products require additional training and skill and may add operating time, but have the potential to mitigate risks associated with tissue dissemination.

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Tissue extraction at the time of gynecologic surgery came under scrutiny after the highly publicized case of a woman whose uterus was removed by laparoscopy in 2013. Although thought to have benign leiomyoma disease preoperatively, the patient was diagnosed with leiomyosarcoma on final pathologic examination. It was presumed that the device used to facilitate tissue removal, an electromechanical, or power, morcellator, worsened her prognosis by spreading this aggressive malignancy. The U.S. Food and Drug Administration (FDA) issued safety communications in 2014 discouraging the use of morcellator devices, arguing alternative methods of tissue removal should be used in the majority of patients.1 As a result, many hospitals banned these devices and the manufacturer of the most widely used morcellator pulled their device from the market.

The exact risk of encountering occult sarcoma during surgery for presumed benign leiomyomas is unknown, but it was estimated at 1 in 352 by the FDA and ranges to fewer than 1 in 5,000 in the reported literature.2 The difference in 5-year survival is estimated at 73% compared with 46% between intact hysterectomy and morcellation cases in one series of patients with occult sarcoma.3 Another series of similar patients did not demonstrate a statistically significant difference in overall survival at 2 years, but patients undergoing morcellation experienced a marked difference in disease-free survival (51% compared with 74%).4 The largest study of this type compared power morcellation, nonpower morcellation, and intact removal of the uterus and showed a nonsignificant difference in recurrence at 3 years (54%, 51%, and 19%, respectively). A difference in overall survival between the two morcellation groups and no morcellation was lost at 3 years.5 Sarcomas are the cancers that mimic benign leiomyomas and seem to represent the majority of risk when it comes to tissue dispersion in these cases. Endometrial hyperplasia or cancer is found at the time of hysterectomy for prolapse more frequently (1–2%),6 but morcellation in these cases does not seem to carry the same negative effects as in sarcoma cases.7,8

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Legal and clinical concerns regarding morcellation and the reduced availability of power morcellators have resulted in a decline in the number gynecologic surgeries performed using a minimally invasive approach, a modality with well-recognized advantages in terms of perioperative complications and convalescence. Several investigators modeled comparative outcomes and costs in decision analyses, demonstrating that risks associated with tissue dissemination at the time of morcellation are balanced by risks associated with the alternative, laparotomy. After consideration of risk factors for malignancy, including age and other less common factors such as prior pelvic radiation or tamoxifen use, properly selected patients may still experience the benefits of minimally invasive surgery even in cases involving enlarged leiomyomas. Surgeons have developed new techniques to accomplish safer morcellation, including specimen fragmentation within a containment bag. Although the surge in innovation regarding tissue extraction initially occurred in response to concerns about occult malignancy, these techniques are also relevant for benign conditions, which can be seeded during these operations as well.

The use of containment bags at the time of tissue morcellation has been reported in the general surgery and urologic literature as well as in gynecologic oncology cases with intentional morcellation of bulky endometrial cancers. For presumed benign leiomyoma disease, there are techniques for containment of morcellation whether using a power morcellator device or performing manual morcellation. Although the benefits remain unproven, there is a theoretical advantage of controlling dissemination of tissue and mitigating risks at the time of tissue fragmentation while permitting a minimally invasive approach even in cases with a grossly enlarged specimen size. This article aims to describe all tissue extraction techniques and offer clinical opinion as to when best to use them. A summary of published abstracts on surgeons' experience with these techniques and accompanying videos can be found in Table 1.

INDICATIONS AND CONTRAINDICATIONS

The indications for morcellation include planned surgery where intact uterine tissue removal is not possible or where the expected benefits of minimally invasive surgery are judged to be outweighed by potential risks of tissue dissemination. These could include open or laparoscopic myomectomy, subtotal hysterectomy, and laparoscopic or vaginal hysterectomy for the enlarged uterus.

In general practice, morcellation of uterine or leiomyoma tissue should not be performed in cases suspicious for malignancy, regardless of the mode of tissue extraction. Relative contraindications to specimen fragmentation include postmenopausal women with new or enlarging leiomyomas and those with personal risk factors such as tamoxifen use, pelvic radiation, or certain hereditary cancer syndromes. Although leiomyosarcoma can occur in young women, the risk of encountering occult malignancy at the time of surgery rises sharply with age. Reflective of this age-related risk, the FDA deems power morcellators specifically are contraindicated in peri- or postmenopausal women. Caution should also be exercised before morcellating tissue in patients with undiagnosed abnormal uterine bleeding. Additionally, patients should be educated about the issues surrounding tissue extraction at the time of minimally invasive surgery and offered laparotomy for intact specimen removal should they prefer that.

PREOPERATIVE EVALUATION

Judicious preoperative evaluation is advised before a procedure involving uterine or leiomyoma morcellation. Although there is no completely reliable method to distinguish benign leiomyoma disease from uterine leiomyosarcoma, it is prudent to make every effort to diagnose a malignancy preoperatively. For a patient undergoing hysterectomy, this includes up-to-date Pap screening and endometrial sampling. Endometrial biopsy has low sensitivity for detection of uterine leiomyosarcoma, but one series demonstrated either positive or suspicious biopsy results in more than 51% of patients who were found to have leiomyosarcoma on final pathology.

Recent pelvic imaging with either ultrasonography or magnetic resonance imaging (MRI) is also recommended. In laparoscopic or robot-assisted laparoscopic myomectomy cases, MRI is more commonly performed as part of surgical planning and may also be useful before hysterectomy in cases of extreme uterine enlargement. Diffusion-weighted or contrast-enhanced MRI in particular has been reported to have utility in detection of leiomyosarcoma, although these findings are based on small series and need to be replicated on a larger scale before being incorporated into routine practice. One study suggested that use of lactate dehydrogenase isoenzyme profile in conjunction with MRI could distinguish degenerating leiomyomas from leiomyosarcoma and may be considered in this clinical scenario. Laboratory testing should include assessment of anemia; one study reported that a hematocrit level below 30% was independently associated with a diagnosis of leiomyosarcoma.
A key limitation of preoperative testing to detect occult leiomyosarcoma is the relative rarity of this condition because the predictive value of screening tests is decreased in situations with low disease prevalence. Even in the presence of a reassuring preoperative workup, occult malignancy may still be present, highlighting the importance of both patient counseling and careful extraction techniques.

TECHNIQUES

Vaginal Morcellation

Vaginal morcellation is the oldest form of tissue fragmentation to remove large specimens in gynecologic surgery, having long been performed in vaginal hysterectomy. Techniques for removing large leiomyoma uteri during vaginal hysterectomy include coring, bivalving, myomectomy, and wedge resection. All of these techniques can be used during total laparoscopic hysterectomy after the uterus and cervix are detached from their pedicles and the vagina. An example of this is the “paper roll” technique, described as placing elevating traction on the cervix and then starting an incision at 6 o’clock and continuing counterclockwise, removing as much uterine tissue as possible during the cut. While making the incision, the cervix is simultaneously rotated downward so that the bulky uterine tissue changes shape and emerges as a tube.

One group estimated the risk of encountering occult uterine malignancy (including endometrial carcinoma) during vaginal hysterectomy with morcellation at 0.82% with no negative effect on outcomes or prognosis.

Although not feasible during a traditional vaginal hysterectomy when morcellation is needed, if the hysterectomy is performed with laparoscopic assistance, it can be contained in a specimen bag before vaginal extraction. The bag is generally introduced through the colpotomy incision and the specimen placed inside. The edges of the bag are brought out through the vagina and the tissue extracted using one of the vaginal morcellation techniques. Bag disruption detected by filling with methylene blue after extraction can occur in as many as one third of cases, so great care must be taken when using this or any morcellation technique. We encourage surgeons to practice with simulation and under guidance of those with experience in the technique when first performing vaginal morcellation.

Vaginal morcellation offers the advantage of maintaining minimal abdominal incisions (eg, all 5 mm or less); thus, we recommend using this approach where feasible during total laparoscopic hysterectomy—usually for patients with adequate vaginal access and uteri less than approximately 800 g. With extremely large uteri, vaginal morcellation is still possible but an abdominal approach may be more efficient. A vaginal approach can also be used for tissue extraction during laparoscopic myomectomy using a posterior colpotomy for introduction of the retrieval bag; a report on this technique did not find any increase in infection, dehiscence, or future development of dyspareunia.

Open Power Morcellation

Mechanical morcellation was first described by Steiner in 1993 with a device that brought tissue out of the abdomen through a cylindrical blade rotated by hand. This innovation revolutionized gynecologic surgery because it facilitated removal of uterine tissue in minimally invasive surgery when vaginal access is limited or unavailable. Eventually morcellation was mechanized with systems using bipolar electrosurgery or an electric motor to drive the blade. The blades come in various sizes and rotate at different degrees of speed and torque. To use these devices, the surgeon holds the blade with the nondominant hand and pulls tissue against the blade with the
dominant hand using a sharp single- or double-toothed tenaculum (Fig. 2A). Power morcellators have been used to remove uterine and leiomyoma tissue during gynecologic surgery as well as in general or urologic surgery for removal of spleens and kidneys.41,42

Lack of visualization, improper use, device malfunction, and surgeon inexperience can lead to inadvertent injury when using any instrument in the operating room, but the consequences of injury with power morcellators are especially grave because these devices are designed to rapidly remove solid organ tissue. Injuries to major vascular structures, including the aorta and vena cava as well as viscera, have been reported.43,44 Continuous visualization of the blade at all times, a clear operative field, and adequate surgical view are essential when using a power morcellator. Foot pedals that activate the motor should be handled with caution and only by the surgeon using the morcellator. The device should be immediately removed and inspected at the first sign of malfunction such as continued blade activation despite release of the activation control. Features such as a large-diameter blade and oscillating function may create less tissue spill at the time of morcellation.45

Regarding dissemination of malignant tissue, studies demonstrating worsened outcomes with morcellation of leiomyosarcoma typically include various methods of tissue fragmentation such as manual morcellation through the vagina or through an abdominal incision in addition to power morcellation techniques.46,47 It is not clear whether there is a differential effect on overall

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**Fig. 1.** Contained vaginal morcellation. **A.** The bag is introduced through colpotomy. **B.** The specimen is brought from the abdomen into the pelvis and surrounded by the bag edges. **C-D.** The edges of the bag are exteriorized through the vaginal opening. **E.** A scalpel is used to morcellate uterine tissue within the bag.


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**Fig. 2.** Power morcellation. **A.** A sharp tenaculum is used to grasp uterine tissue and pull it against a motorized blade. **B.** Small fragments are created with power morcellation and must be systematically removed to prevent parasitic growth of tissue. **C.** Power morcellation contained within a specimen bag facilitates more thorough collection of tissue fragments.


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survival, but disease-free survival may be specifically decreased with use of power morcellation compared with other morcellation techniques.\textsuperscript{5,48}

Aside from concerns with spread of malignant tissue, power morcellators can also disseminate benign tissue such as endometriosis, adenomyosis, and leiomyomas.\textsuperscript{20,49} These cases can present with patient-reported symptoms of abdominal pain or can be noted as an incidental finding on subsequent imaging. Leiomyoma tissue has also been reported in trocar incisions and as diffuse leiomyomatosis,\textsuperscript{50} although the latter can occur after abdominal myomectomy or de novo so the additional attributable risk associated with power morcellation is difficult to estimate. Furthermore, leiomyoma cells can be detected in the abdomen after myoma extraction but before morcellation in laparoscopic myomectomy as well as laparotomic myomectomy,\textsuperscript{51,52} suggesting that tissue extraction is not the only opportunity for cellular spread at the time of gynecologic surgery.

Gynecologic surgeons should carefully restrict the use of power morcellation devices at the time of uterine or leiomyoma surgery and be aware of the FDA statement that laparoscopic power morcellators are contraindicated for removal of leiomyoma tissue in perimenopausal or postmenopausal women.\textsuperscript{1} If a surgeon chooses to use power morcellation without a tissue containment system, best practices should include careful, systematic examination of the peritoneal cavity, including liberal irrigation after tissue extraction to look for any residual tissue fragments that might recruit blood supply, implant, and grow (Fig. 2B).

**Contained Power Morcellation**

The concept of contained power morcellation for uterine or leiomyoma specimens was first described as part of a single-port procedure for laparoscopic supracervical hysterectomy.\textsuperscript{53} The specimen is placed within a containment bag, which is in turn insufflated to create a protected and enclosed space. The morcellator device is then used as described within the confines of the containment bag and under continuous laparoscopic visualization (Fig. 2C). A multisite prospective study confirmed the feasibility of this process using either a single-port or multiport approach,\textsuperscript{24} and many descriptions of variations have been reported.\textsuperscript{53–57}

During the early adoption phase, the reports on this technique involved containment bags that were not specifically designed for this purpose. A study on bag integrity at the time of multiport-contained power morcellation (which involved intentional puncture of the bag to allow for introduction of a camera port) reported 9% incidence of leakage of unknown clinical significance.\textsuperscript{58} There is now an FDA-approved device for contained power morcellation with a single-port approach (Fig. 3),\textsuperscript{59} and other products have been developed for a multiport approach as well.\textsuperscript{60–62} For very large specimens, significant tissue manipulation may be needed to contain the specimen, which could theoretically disrupt tissue planes and expose tumor cells. On the other hand, in myomectomy cases, tissue planes are intentionally disrupted to extract the tumors, but it seems reasonable to use as much caution as is feasible in keeping specimens and bags intact. Even with use of a containment system, the FDA recommendations remain in effect.\textsuperscript{1}

The addition of a containment system to the power morcellation process does not appear to create new complications or negatively affect perioperative outcomes. However, it may be associated with longer operative time. The process of introducing a large containment bag and enclosing the specimen under laparoscopic guidance can be particularly burdensome during a surgeon’s initial learning phase. Retrospective reports suggest that, on average, 20–26 minutes of additional time are required to accomplish contained power morcellation compared with open power morcellation.\textsuperscript{63,64} However, a randomized trial of open or contained power morcellation at the time of myomectomy found no difference in morcellation time, total operative time, or simplicity of morcellation.\textsuperscript{65}

There is a paucity of long-term data regarding outcomes related to contained power morcellation, particularly in cases of unintentional morcellation of a malignancy. A case report of a single-port laparoscopic supracervical hysterectomy and contained morcellation of a high-grade leiomyosarcoma demonstrated no recurrence with 2 years of follow-up.\textsuperscript{66} There is a lack of equipoise to study this topic in a prospective fashion, and it may be several years before potential sequelae of contained power morcellation can be fully assessed. Although the exact degree of protection provided by containment systems is not clear, it is logical that containing the morcellation process should mitigate many risks associated with morcellation. The bag-puncture method maintains small (less than 12 mm) laparoscopic incisions while potentially reducing the likelihood of leaving tissue inside the abdomen, but these bags were not intended for this purpose and there is a relatively high leakage rate. The single-incision contained power morcellation system uses a slightly larger incision at the umbilicus; however, the bag is kept intact and at present this is the only FDA-approved system for contained power morcellation.
Minilaparotomy Morcellation

A small abdominal incision can also be used to morcellate tissue using a scalpel. The most common sites chosen for this include extension of an existing umbilical or suprapubic trocar incision or a Pfannenstiel location. These incisions typically range from 2 to 4 cm, with smaller incisions offering better cosmesis and larger incisions providing more rapid extraction of tissue. Incisional hernia is generally considered to be a risk associated with larger incisions, but there does not appear to be an increased risk of hernia in gynecologic laparoendoscopic single-site surgery with umbilical incisions up to 2 cm.

Retrospective comparative studies suggest no significant differences in outcomes or complications between manual extraction and power morcellation. One study suggests minilaparotomy may be associated with a longer hospital stay or increased wound complications; however, these authors grouped together cases in which minilaparotomy was used solely for tissue extraction with cases in which the entire surgery was performed through an incision up to 6 cm. Another study of laparoscopic cases demonstrated longer operative times with manual morcellation, regardless of the use of containment bags.

The fascial incision can be extended beyond than the small skin incision and a disposable self-retracting ring retractor used to maximize horizontal and vertical space, facilitating extraction by bringing tissue closer to the abdominal surface. A sharp instrument such as a penetrating towel clamp or Lahey clamp is used to grasp the tissue and provide continual upward traction with the nondominant hand while the dominant hand makes semicircular incisions on the tissue, typically with a No. 11 scalpel blade. The clamp is used to rock the tissue back and forth in a motion opposing the circular incisions, changing the shape of the tissue into a tube that can fit through the minilaparotomy (Fig. 4).

One group coined the technique “ExCITE,” or Extracorporeal C-Incision Tissue Extraction, in a report describing troubleshooting common intraoperative problems as well as options to practice using a low-cost simulation model.

Specimen bags can also be used with manual morcellation. The bag is introduced through an abdominal incision or through colpotomy after total laparoscopic hysterectomy. The specimen is placed into the bag under direct laparoscopic visualization. To facilitate this process, it is advisable to place the specimen into the abdomen, orient the bag in the pelvis, reverse some Trendelenburg position, and pull the specimen down from the abdomen into the open bag. The bag is elevated around the tissue to fully encapsulate it and the edges of the bag brought out of the incision that will be used for morcellation. The incision is extended to the desired size and extraction carried out as described previously, with or without the addition of a self-retracting ring retractor. The only FDA-approved...
system for contained manual extraction at present also includes a plastic incision guard, which protects against bag or organ injury during morcellation. Many other specimen bags of varied shape, size, and material have been used for manual extraction, including those with self-deployment mechanisms, an easy and familiar technique suitable for smaller specimens. We recommend minilaparotomy morcellation for cases with limited or no vaginal access, very large specimens, and in obese women. We also recommend using a containment system in all minilaparotomy cases where feasible.

DISCUSSION

Patient-centered care demands incorporating individual preferences and risk tolerance regarding morcellation-related outcomes into the approach for leiomyoma surgery. During informed consent, physicians should discuss the risks and benefits of various approaches to surgery for large leiomyomas related to tissue dissemination and otherwise (eg, cosmesis, thromboembolism, hernia, wound infection, mortality). In most cases, minimally invasive surgery (vaginal, laparoscopy) carries quantitatively lower risk overall. The various methods of tissue extraction in minimally invasive surgery and the associated risks and benefits, including elements such as incision size and location as well as operative time associated with containment, should be provided so that women can make an informed decision on the best approach in each situation.

It is not possible to completely avoid exposing tumor cells during surgery for leiomyomas in all cases (eg, myomectomy, vaginal hysterectomy for the larger uterus, subtotal hysterectomy), but we advocate for using strategies to minimize exposure wherever possible. This starts with choosing appropriate candidates for fragmented tissue extraction and containing tissue where feasible. We use contained manual morcellation (vaginal or minilaparotomy) in the majority of our laparoscopic cases and for one author, power morcellators are not even available based on institutional policy. For those still using power morcellators, we recommend carefully limiting use given the strong wording of the FDA and the current legal environment. Even considering the risk of bag leakage, it stands to reason that one is less likely to leave behind residual uterine tissue when a containment strategy is used. Additional risks of containment systems—slightly larger incision size, increased operative time, sometimes challenging tissue manipulation—have not been systematically quantified with decision analysis or cost-effectiveness studies. Our opinion, however, is that in most cases, these risks are outweighed by the real or perceived gravity of potential tissue dispersion of malignant tissue.

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