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Review Article

# Complications of Energy Devices in Laparoscopic Gynecology: A Comprehensive Review of Electrosurgical and Non-Electrical Modalities

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**Abstract**

Laparoscopic gynecology increasingly relies on energy-based devices for tissue dissection, coagulation, and vessel sealing. Traditional electrosurgery, comprising monopolar and bipolar modalities, remains widely used for its versatility and cost-effectiveness but carries risks such as insulation failure, stray-current injury, capacitive coupling, and unintended lateral thermal spread, which may result in delayed or occult organ damage. Over the past two decades, advanced “non-electrical” energy systems, including ultrasonic devices, advanced bipolar vessel sealers, hybrid ultrasonic-bipolar instruments, plasma energy, and lasers, have been introduced to enhance precision and potentially reduce collateral thermal injury. This review summarizes complications associated with electrosurgical and non-electrical energy devices in gynecologic laparoscopy, highlighting their mechanisms, severity, and risk factors. Each device demonstrates unique complication patterns: electrosurgery is prone to delayed bowel and ureteric injuries; ultrasonic systems can cause mechanical–thermal bite injuries or ureteral transection; plasma energy generally induces superficial necrosis but may rarely lead to fistula formation; laser systems are limited by smoke plume and visibility, potentially causing under-coagulation; and advanced bipolar sealers may produce lateral thermal spread or seal failure under certain conditions. Comparative evidence indicates that overall complication rates are similar across modalities, emphasizing that surgeon technique, tissue handling, and adherence to energy safety principles are more critical determinants of outcome than the type of device used. Understanding the biophysical principles, thermal profiles, and limitations of each energy source is essential for optimizing safety and efficacy in minimally invasive gynecologic surgery.

**Keywords:** Laparoscopic gynecology; Electrosurgery; Ultrasonic energy; Advanced bipolar; Plasma energy; Laser surgery; Complications; Energy devices

## Introduction

Laparoscopic gynecology relies extensively on energy-based devices for cutting, coagulation, dissection, and vessel sealing. Traditional electrosurgery, comprising monopolar and bipolar modalities, has long served as the foundation of minimally invasive surgery because of its availability, cost-effectiveness, and versatility. However, electrosurgery introduces well-recognized risks, including insulation failure, capacitive and direct coupling, stray current injuries, and excessive lateral thermal spread. These mechanisms, often not visible intraoperatively, may lead to occult injuries of adjacent structures such as bowel, bladder, ureter, or abdominal wall musculature, sometimes presenting only after several postoperative days [1].

Over the past two decades, multiple “non-electrical” or advanced energy systems have been introduced in gynecologic laparoscopy. These include ultrasonic shears, advanced bipolar vessel sealers with impedance-controlled feedback, hybrid ultrasonic-bipolar devices, lasers, and plasma-based energy systems. Ultrasonic devices convert electrical energy into high-frequency mechanical vibration, cutting and coagulating tissue without passing electric current through the patient, thereby eliminating stray electrical injury while potentially reducing thermal spread [2]. Advanced bipolar sealers, such as LigaSure and Enseal, incorporate pressure-controlled energy delivery with automatic impedance monitoring to optimize vessel sealing up to 7 mm with minimal collateral damage [3].

Despite their perceived advantages, no energy device is entirely free from complications. Ultrasonic shears may still cause unintended thermal injury due to residual blade heat, particularly in confined anatomical spaces. Advanced bipolar devices may produce delayed tissue necrosis, carbonization, or suboptimal sealing when improperly used or applied to thick or inflamed pedicles. Comparative studies indicate that although advanced systems may reduce operative time or blood loss, their overall complication rates do not demonstrate clear superiority over traditional electrosurgery [3]. Therefore, safe surgical practice requires a detailed understanding of the operating principles, thermal characteristics, and limitations of each device type.

**Electrosurgical Devices and Their Complications**

Monopolar and bipolar electrosurgery function by delivering high-frequency alternating current to generate heat for tissue cutting, desiccation, or coagulation. Their inherent mechanisms predispose them to distinct complications, primarily through unintentional energy spread. Lateral thermal spread, insulation failure, direct coupling, and capacitive coupling remain the most common mechanisms leading to unrecognized organ injury. Because electrosurgical thermal effects often extend deeper than what is visibly apparent, clinical manifestations may be delayed for days, increasing morbidity when diagnosis is missed [4].

**Bowel Injury**

Electrosurgical bowel injury is one of the most severe complications in gynecologic laparoscopy. Small bowel loops may lie close to operative sites without being visible, making them vulnerable to stray or excessive thermal spread. Delayed perforation typically manifests 2–7 days after surgery due to progressive tissue necrosis from thermal insult [4]. Early symptoms—abdominal pain, fever, leukocytosis, or ileus—are nonspecific, delaying diagnosis. Delay significantly increases the risk of peritonitis, sepsis, and the need for emergency reoperation. Preventive strategies include minimizing activation time, applying the lowest effective energy level, avoiding blind coagulation, and ensuring constant visualization of the active electrode [3].

**Ureteric Thermal Necrosis**

Monopolar or bipolar energy used near the infundibulopelvic ligament, uterine artery, or pelvic sidewall may injure the ureter through thermal spread extending beyond visible boundaries. Even a small thermal insult can cause ureteric ischemia or necrosis due to its limited blood supply [4]. Clinical presentation may include delayed flank pain, urinary leakage, hydronephrosis, ureterovaginal fistula, or fever. Injury risk increases in cases with distorted anatomy, such as endometriosis or pelvic adhesions. Using energy-lowering techniques, precise dissection, or switching to ultrasonic/advanced bipolar devices may reduce risk when operating near the ureter [5].

**Insulation Breakdown Injuries**

Insulation failure occurs when microscopic defects in instrument sheathing allow current to escape, leading to deep burns outside the surgeon's visual field. Repeated use, autoclaving, and mechanical wear increase this risk. These injuries often involve bowel, omentum, or abdominal wall musculature and may go unrecognized intraoperatively [4]. Proactive mitigation includes thorough inspection of insulation, avoiding reuse of compromised instruments, and incorporating active electrode monitoring (AEM) technology, which significantly reduces insulation-related injuries [1].

**Stray Current Burns (Capacitive and Direct Coupling)**

Stray current injury occurs when unintended transfer of electrical energy happens between instruments or between an active electrode and adjacent conductive materials. Direct coupling results from accidental contact between active and inactive instruments, while capacitive coupling involves current transfer across intact insulation due to induced electric fields [3]. These mechanisms can cause severe visceral burns even during apparently safe techniques. Preventive steps include using all-metal grounded trocars, avoiding simultaneous instrument activation, and preferring cutting modes with lower voltage requirements.

**Excessive Smoke Reducing Visibility**

Electrosurgical smoke contains particulate matter, carcinogens, and bioaerosols. Dense smoke reduces visibility, obscures tissue planes, and increases the risk of inadvertent injury by impairing depth perception and prolonging surgical time [6]. Smoke exposure also carries health risks for operating-room staff. Dedicated smoke evacuation systems significantly improve visualization and help prevent energy-related complications.

**Ultrasonic Energy (Harmonic) and Complications**

Ultrasonic devices operate by generating mechanical vibrations at approximately 55 kHz, creating cutting and coagulation through frictional heat and protein denaturation rather than electrical current passage. Peak temperatures are lower than in monopolar electrosurgery, reducing but not eliminating thermal risk [2]. They are widely used for adnexal dissection, adhesiolysis, endometriosis surgery, and vessel sealing around sensitive structures.

Despite perceived safety, several complications have been documented. Case reports describe ureteral transection, ureterovaginal fistula, and pelvic sidewall injuries associated with ultrasonic devices, particularly when anatomy is distorted by adhesions or adnexal masses [5]. The blade of the device remains hot for several seconds after activation, making residual heat a common mechanism of unintended injury when the instrument is repositioned too quickly [2]. Incomplete hemostasis can occur when sealing vessels greater than 3–4 mm or when tissue tension is suboptimal, sometimes requiring adjunctive bipolar or suturing techniques [3].

**Common complications include:**

- Thermal injury to the ureter when dissecting near the infundibulopelvic ligament or deep pelvic sidewall [5]
- Incomplete hemostasis, leading to postoperative bleeding or the need for additional energy application
- Residual jaw heat burns, particularly during rapid movement after long activation cycles [2]

Overall, ultrasonic systems are effective and precise but require controlled activation times and heightened awareness of residual heat near delicate structures.

**Advanced Bipolar Vessel Sealers (LigaSure, Enseal) and Complications**

Advanced bipolar energy combines compression with radiofrequency energy to create consistent, durable vessel seals up to 7 mm. Feedback-controlled impedance monitoring limits overheating and provides predictable results with relatively narrow thermal spread (1–3 mm) [3]. These devices are frequently used for sealing uterine vessels, IP ligaments, and broad-ligament pedicles.

While advanced bipolar sealers offer advantages such as reduced operative time and blood loss compared with conventional bipolar energy, complications may still occur. Thermal spread remains a major concern, particularly when sealing thick or inflamed tissue bundles, potentially leading to bladder, bowel, or ureteric burns [3]. Repeated activation can increase thermal dispersion, especially in fibrotic tissue associated with endometriosis. Seal failure is another clinically significant issue. Inadequate compression, improper device angulation, or suboptimal tissue tension may lead to postoperative hemorrhage, hematoma, or delayed secondary bleeding [3]. Excessive charring during prolonged activation also generates smoke, obscures visualization, and may increase adhesion formation.

Common complications include:

- Thermal spreads causing bowel or bladder injury, especially in fibrotic or inflamed tissue [3]
- Seal failure resulting in postoperative hematoma or delayed bleeding
- Carbonization and smoke, impairing visualization and increasing operative difficulty

Although advanced bipolar devices are generally safe and effective, their optimal use requires careful attention to activation times, tissue thickness, and proper compression technique.

**Plasma Energy (PlasmaJet, Argon Plasma) and Complications**

Plasma-energy systems (e.g., PlasmaJet, neutral argon plasma) deliver ionized gas for non-contact vaporization, ablation, and superficial coagulation, avoiding electrical current flow through tissues. Pilot studies in gynecologic laparoscopy demonstrate minimal lateral thermal spread (<1 mm) and effective peritoneal ablation in endometriosis, with no intra- or postoperative complications in early series (n=20) [7]. Similar findings were reported in oncologic cytoreductive surgery, where neutral argon plasma produced significantly less thermal damage than bipolar electrocoagulation on histological analysis [8].

Reported advantages include controlled depth of action, reduced smoke generation, and precise treatment of superficial lesions [7,9]. However, despite these safety features, data on major complications remain limited. A systematic review of plasma-based cytoreduction reported very low morbidity, with only isolated complications such as pneumothorax during extensive diaphragmatic stripping (not directly attributable to plasma energy) [9]. Nevertheless, theoretical risks include bowel injury during treatment of deep infiltrating endometriosis, delayed necrosis with prolonged exposure, and potential gas-related complications (overpressure, embolism) when argon flow is not well controlled [10].

Risk scenarios include Treatment in poorly visualized fields, ablation over dense adhesions or deep infiltrating lesions, prolonged or high-flow activation, all of which may increase thermal penetration or mechanical impact of ionized gas. Overall, plasma energy appears safe in preliminary studies, but the absence of large, controlled trials means that its complication profile is not yet definitively established.

**Laser Energy and Complications ($CO_2$, Nd:YAG, Diode)**

Laser systems allow precise cutting, vaporization, and ablation, with tissue effects dependent on wavelength, beam mode, and water absorption. $CO_2$ lasers provide extremely superficial penetration, whereas Nd:YAG and diode lasers reach deeper tissues. Although lasers have been widely used for peritoneal endometriosis, adhesiolysis, and fertility-sparing procedures, several limitations and complications are described in contemporary reviews [11].

Laser-associated complications arise from smoke plume, impaired visualization, variable depth of thermal injury, and inadequate coagulation, which may lead to intraoperative bleeding and


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conversion to electrosurgery. Additionally, laser systems carry unique hazards, including fire risk, reflected-beam tissue damage, and ocular injury, requiring rigorous safety protocols (eye shields, smoke extraction, non-reflective instruments) [11].

Clinical experience shows that lasers are effective for superficial lesion ablation but are less suitable for complex dissections involving bowel, bladder, deep endometriosis, or dense adhesions, where thermal injury or bleeding is more likely [6]. Modern reviews note that, despite their precision, lasers are now less commonly used in gynecologic laparoscopy, largely replaced by ultrasonic and advanced bipolar devices that offer superior hemostasis, greater maneuverability, and less plume generation [12]. Tble 1. Shows the comparison between the electrosurgical and non-electrosurgical devices in Laproscopic surgery in terms of the complications.

| **Energy Type** | **Common Complications** | **Severity** | **Mechanism of Injury** | **Supporting Study** |
|---|---|---|---|---|
| **Electrosurgery (Monopolar/Bipolar)** | Thermal spread, delayed bowel burns, insulation failure injury, capacitive coupling, nerve injury | Moderate–Severe | Thermal conduction, stray energy | Mettler L, et al., Gynecological Endoscopy (2008) [13] |
| **Ultrasonic (Harmonic Scalpel)** | Less thermal damage, but risk of mechanical or thermal edge injury | Mild–Moderate | Mechanical vibration & lower heat generation | Harrell AG et al., Surg Endosc (2004) [14] |
| **Advanced Bipolar (LigaSure)** | Vessel burst pressure failure, thermal lateral spread | Moderate | Confined thermal energy | Kennedy JS et al., Surg Endosc (1998) [15] |
| **Laser** | Eye injury, smoke production, deep thermal injury | Moderate–Severe | Direct photothermal damage | Schonauer C et al., Lasers Med Sci (2002) [16] |

**Table 1:** Comparison of Complications Between Electrosurgical and Non-Electrosurgical Energy Devices in Laparoscopic Surgery

**Comparative Evidence**

Systematic reviews and comparative evaluations indicate that while energy sources differ in thermal mechanics, overall complication rates do not significantly differ between electrosurgical, ultrasonic, plasma, laser, and advanced bipolar systems during gynecologic laparoscopy [17]. The relative safety of each device is influenced more by surgeon experience, activation time, tissue load, and adherence to safe energy principles than by the energy modality itself.

Each technology, however, exhibits distinctive injury patterns:

- **Electro surgery:** Most associated with stray current injuries, insulation failure, and delayed bowel injury due to concealed thermal spread. Such complications may present 24–72 hours postoperatively, reflecting deeper-than-anticipated tissue penetration.
- **Ultrasonic devices:** Although operating at lower temperatures, they can produce mechanical–thermal bite injuries with risks of ureteric transection in limited pelvic spaces, where lateral vibration affects adjacent structures.
- **Plasma energy systems:** Typically result in superficial coagulative necrosis with controlled penetration; however, prolonged exposure or use in dense endometriosis may cause submucosal injury or, rarely, delayed fistula formation.
- **Laser systems:** Provide high precision but are limited by smoke plume and reduced visibility, leading to under-coagulation or bleeding when beam alignment is suboptimal.
- **Advanced bipolar vessel sealers:** Demonstrate thermal spread comparable to conventional bipolar instruments, with risks including seal failure, lateral thermal injury, and charring in confined surgical fields.

Overall, evidence supports that no single energy modality is universally safer; instead, proper technique, device knowledge, and thermal safety practices are the critical determinants of preventing injury during laparoscopic gynecologic surgery [17].

**Conclusion**

Energy devices are indispensable in gynecologic laparoscopy, yet each modality carries unique thermal and mechanical risks that require careful technique and device-specific understanding. Current evidence shows no clear superiority of one energy source over another, underscoring that surgeon expertise, appropriate settings, and situational judgment ultimately determine safety. Continued training and adherence to energy safety principles remain essential to minimizing complications.

**List of Abbreviations**

- IP ligament – Infundibulopelvic ligament
- $CO_2$ – Carbon Dioxide

- Nd:YAG – Neodymium-doped Yttrium Aluminum Garnet
- AEM – Active Electrode Monitoring
- JSLS – Journal of the Society of Laparoendoscopic Surgeons
- PLoS One – Public Library of Science One
- OBG Manag – Obstetrics & Gynecology Management
- kHz – Kilohertz

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