Introduction

Women who undergo adnexal surgery experience a decrease in reproductive function postoperatively [1-8]. The observed decrease in ovarian function may be due in part to thermal injury associated with energy sources used for hemostasis, dissection, and excision. There are several available modalities of energy with varied tissue effects. Electrosurgery has traditionally been performed with monopolar and bipolar devices. In monopolar surgery, electrical current passes through one electrode to the tissue and moves through the patient to complete its current cycle, whereas in bipolar surgery, the current is confined to the tissue between the two electrodes of the surgical instrument. Bipolar devices typically use a lower voltage than monopolar units for hemostasis, and result in more limited thermal spread compared to monopolar instruments [9].

When monopolar electrical current is applied to tissue, possible outcomes include vaporization, fulguration, and desiccation [9-10]. The “cut” mode generates a current as a continuous sinusoidal waveform, whereas the “coagulation” mode delivers energy in an interrupted fashion, requiring higher voltage than the cut mode to confer the same amount of power [10]. Non-contact activation on the “cut” setting generates intense heat over a small surface area, resulting in temperatures above 100°C and vaporization of tissues. Fulguration is non-contact coagulation achieved by sparking tissue in the coagulation mode, which results in tissue destruction and often generates temperatures greater than 200°C. Finally, direct tissue contact with the electrode results in desiccation and coaptation (coagulum formation and vessel sealing) [9-10]. Bipolar devices work through contact activation, and similarly result in desiccation and coaptation.

Ultrasonic devices are an alternative energy source for coagulation and cutting [9]. No electrical current is generated by ultrasonic energy; rather, mechanical energy and heat cause protein denaturation and the development of a coagulum. Cutting is achieved with the ultrasonic scalpel through its vibrating blade tip, which results in large pressure and vaporization of cells at low temperature, achieving precise cutting and dissection. Ultrasonic energy is thought to achieve comparable hemostasis with minimal thermal spread compared to traditional electrosurgical devices [9-11]. Data comparing the thermal spread of monopolar, bipolar, and ultrasonic devices in a porcine model show that monopolar instruments result in the highest temperature and greatest degree of lateral thermal spread, reaching temperatures above 100°C (mean 0.99 ± 0.82 mm), whereas the helium plasma device produced the smallest injury (mean 0.57 ± 0.4 mm) (p = 0.018). In uterine tissue, the bipolar instrument produced the greatest depth of injury (mean 1.15 ± 0.2 mm) and plasma device resulted in the lowest level of injury (mean 0.42 ± 0.13 mm) (p = 0.0002). The ultrasonic shears also resulted in less injury to the uterus than the bipolar device (mean 0.48 ± 0.23 mm) (p = 0.0027).

Conclusion: Helium plasma energy may represent a less injurious alternative to the monopolar device for use during adnexal surgery.

Key words: Electrosurgery; Plasma energy; Gynecology; Ovary; Thermal injury.
Peratures greater than 42°C at 1 cm away from the tip of the instrument, at which point damage to cell membranes and protein denaturation occurs. Little difference was seen in this study between bipolar and ultrasonic energy devices [12].

Plasma represents another alternative energy source created by passing an inert gas over an electrically charged surgical blade designed to energize the gas to a plasma stream for coagulation and dissection [13]. Data from a porcine model suggest that helium plasma energy may have less thermal spread than monopolar devices [13], but its effects on ovarian histology have not been compared to other electrosurgical modalities. Because of the decrease in post-operative reproductive function among women who undergo adnexal surgery, it is critical to minimize thermal injury. In this study, the authors compare the histologic effects of the monopolar, bipolar, ultrasonic, and helium plasma energy sources on the ovary and uterus in a porcine model.

Materials and Methods

After approval from the Institutional Animal Care and Use Committee, eight non-pregnant, adult female pigs weighing 35-45 kg were obtained for inclusion in this study. The animals were intubated, sedated under general anesthesia, and placed in a dorsal supine position. Their abdomens were then shaved, prepped with betadine, and draped in the standard fashion for laparotomy. A midline laparotomy incision was made, and the ovaries and uterine horns were identified. In order to minimize waste, animals used in this study were also used for resident surgical education. Laparotomy was performed for educational purposes, and the research protocol was performed after completion of the resident training protocol. Although the study was not performed under laparoscopic conditions, laparoscopic instruments were used.

Thermal injuries were created on the ovaries and uterine horns using bipolar Kleppinger forceps at 30 W, the monopolar pencil at 30 W, the ultrasonic Harmonic Ace shears at power setting 3 (min), and the helium plasma energy device at 20% power. A spatula electrode was used on the monopolar pencil, and the shaft of the device was placed in contact with the tissue. The injuries were mapped out by energy source, organ laterality, and location relative to the ovarian hilum. This was done to ensure that thermal injuries were equally distributed across different anatomic locations and areas of varied vascularity in order to mimic clinical energy applications. Each device was activated for five seconds. The plasma device was held 5 mm above the tissue, and the other three devices were activated in direct contact with the tissue. Two injuries were made on each uterine horn (n = 32), and one thermal injury was made on each ovary (n = 16). One ovary was large...
Our study evaluated the histologic effects of four energy sources on ovarian and uterine tissues in a porcine model, with the primary goal of identifying a device that minimizes thermal injury to the ovary. A number of studies have reported decreased ovarian reserve after ovarian cystectomy, with up to a 30% decrease in anti-Müllerian hormone (AMH) levels after unilateral cystectomy and up to a 50% decrease after bilateral cystectomy [1-8]. Goodman et al. demonstrated that surgical excision of endometriomas has a detrimental effect on AMH levels that persists at six months postoperatively; therefore, identifying a device that minimizes injury to the ovary is critical for women of reproductive age undergoing adnexal surgery [1-8].

The mean depth of thermal injury to ovarian tissue was lowest for the plasma energy device and highest for the monopolar pencil. Although the ultrasonic shears and the bipolar device also demonstrated lower mean depths of injury than the monopolar pencil, these differences did not reach statistical significance.

These data suggest that helium plasma energy may represent a less injurious alternative to monopolar for excising ovarian endometriosis or obtaining hemostasis during adnexal surgery. Parsa published a report of retroperitoneal dissection of an ovarian endometrioma adherent to the rectosigmoid colon using the same helium plasma device evaluated in this study, demonstrating that the minimal thermal spread of the device allows for complete treatment of endometriosis in close proximity to bowel [14]. Further study

### Table 1. — Mean depth of thermal injury in ovarian and uterine tissue.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Ovarian tissue</th>
<th>Uterine tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean depth of injury + standard deviation</td>
<td>Mean depth of injury + standard deviation</td>
</tr>
<tr>
<td>Bipolar</td>
<td>0.57 ± 0.40 (mm) (n = 15)</td>
<td>1.15 ± 0.20 (mm) (n = 32)</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>0.41 ± 0.27 (mm) (n = 27)</td>
<td>0.48 ± 0.23 (mm) (n = 32)</td>
</tr>
<tr>
<td>Helium plasma</td>
<td>0.11 ± 0.04 (mm) (n = 15)</td>
<td>0.42 ± 0.13 (mm) (n = 32)</td>
</tr>
<tr>
<td>Monopolar</td>
<td>0.99 ± 0.82 (mm) (n = 15)</td>
<td>0.72 ± 0.25 (mm) (n = 32)</td>
</tr>
</tbody>
</table>

### Table 2. — Energy source comparisons.

<table>
<thead>
<tr>
<th>Energy Source Comparison</th>
<th>Adjusted p-value for ovarian tissue</th>
<th>Adjusted p-value for uterine tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipolar vs. ultrasonic</td>
<td>0.82</td>
<td>0.002</td>
</tr>
<tr>
<td>Bipolar vs. plasma</td>
<td>0.09</td>
<td>0.0002</td>
</tr>
<tr>
<td>Bipolar vs. monopolar</td>
<td>0.70</td>
<td>0.08</td>
</tr>
<tr>
<td>Ultrasonic vs. plasma</td>
<td>0.12</td>
<td>0.56</td>
</tr>
<tr>
<td>Ultrasonic vs. monopolar</td>
<td>0.64</td>
<td>0.18</td>
</tr>
<tr>
<td>Monopolar vs. plasma</td>
<td>0.02</td>
<td>0.06</td>
</tr>
</tbody>
</table>

*p-values generated using Dunn’s test with Benjamini Hochberg adjustment for false discovery.
is required to determine whether a decrease in the depth of thermal injury correlates with improved surgical and reproductive outcomes in women undergoing gynecologic surgery.

As with other energy sources, the tissue effects of plasma devices are determined by tissue conductivity, current density, and activation time [9-10]; therefore it is critical to evaluate thermal effects specifically in the tissue of interest. To the present authors’ knowledge, this study is the first to evaluate the histologic effects of plasma energy in ovarian tissue. A prior study comparing thermal spread of a plasma energy device to the monopolar pencil, argon beam coagulator, and CO2 laser on porcine bladder, peritoneum, and small intestine, found that the plasma instrument demonstrated decreased mean depth of thermal injury in all three tissue types compared to other devices [13]. Mean thermal spread for the monopolar (0.72–0.82 mm), bipolar (0.4–1.1 mm), and ultrasonic (0.4–0.48 mm) devices recorded in this study are within the range of those reported throughout the literature [13, 15-17]. Consistent with the results of thermal injury to uterine tissue in this study, a prior investigation of ultrasonic devices resulted in more tissue damage than monopolar and bipolar devices at 80% power with a type 1 error rate of 5%, 13 samples would be required in each energy group for a total of 52 pigs. Additionally, further study must be undertaken to determine whether a decrease in thermal injury correlates with improved postoperative ovarian function in women undergoing gynecologic surgery.

The primary limitation of this study was the sample size. After adjusting for multiple comparisons, in order to detect a 0.5 mm difference in depth of thermal injury between the bipolar and plasma devices at 80% power with a type 1 error rate of 5%, 13 samples would be required in each energy group for a total of 52 pigs. Additionally, further study must be undertaken to determine whether a decrease in thermal injury correlates with improved postoperative ovarian function in women undergoing gynecologic surgery.

![Figure 2](image_url) — Median depth of thermal injury in ovarian tissue with first and third quartiles marked. Statistically significant p-values obtained using Dunn’s test are annotated in the figure.

![Figure 3](image_url) — Median depth of thermal injury in uterine tissue with first and third quartiles marked. Statistically significant p-values obtained using Dunn’s test are annotated in the figure.

**Acknowledgement**

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**References**


Thermal injury to the ovary and uterus in a porcine model: a comparison of four energy sources


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