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Original Research

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

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Summary

Background: Laparoscopic energy results in thermal injury to the ovary during adnexal surgery that may contribute to a decrease in reproductive function postoperatively. Plasma energy is an alternative to traditional laparoscopic energy sources that is 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. Data suggest that plasma may have less thermal spread than traditional energy sources, but its effects on ovarian histology have not been compared to other electrosurgical modalities. *Materials and Methods:* Thermal injuries were created on porcine ovaries and uterine horns with bipolar forceps, monopolar pencil, ultrasonic shears, and a helium plasma device. The depth of thermal injury was evaluated histologically. *Results:* Monopolar electrosurgery resulted in the greatest depth of thermal injury in ovarian tissue (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.

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 tem-

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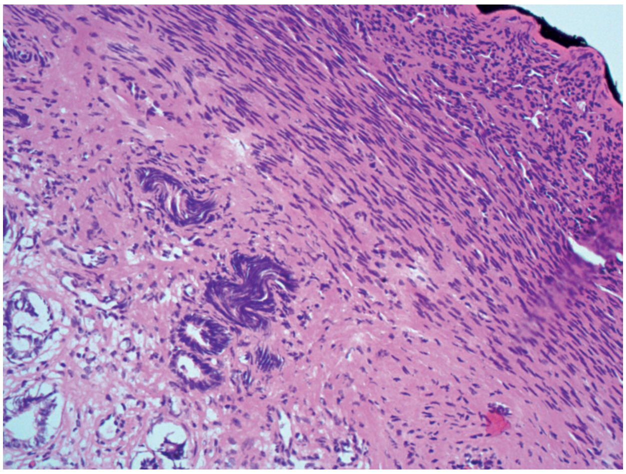

Figure 1A. — Histologic changes in uterine tissue due to thermal injury (ultrasonic device). The cautery effect extends from the uterine serosa (upper right) to involve basils endometrial glands (center left). The elongate smudgy nuclei and homogeneous eosinophilic smooth muscle and stroma within the cautery effect contrast sharply with the unaffected endometrial glands and stroma (lower left). Hematoxylin and Eosin staining.

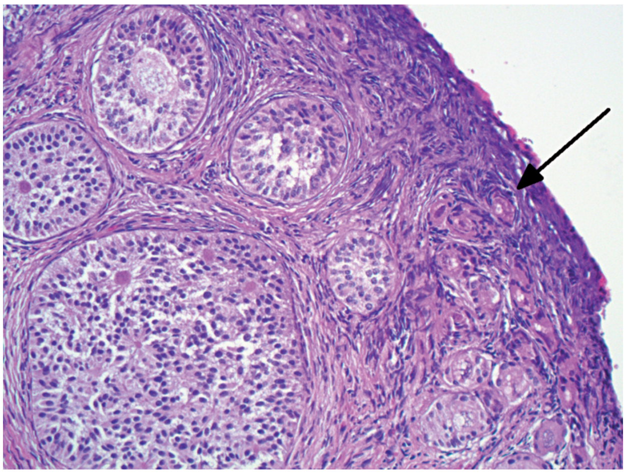

Figure 1B. — Histologic changes in ovarian tissue due to thermal injury (helium plasma device). The surface of the ovary is seen at the upper right. The cautery effect involves a thin band of superficial ovarian cortex including multiple mostly primordial follicles (arrow). Hematoxylin and Eosin staining.

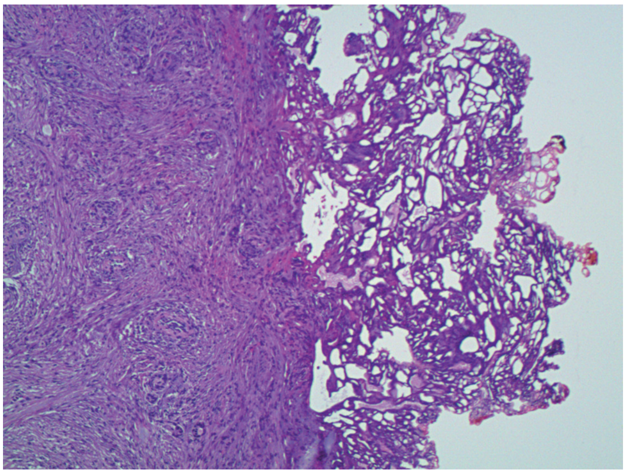

Figure 1C. — Severe disruption of ovarian tissue (bipolar device). The cautery effect is more dramatic in this ovary. Note the severe tissue disruption and vacuolization involving the ovarian surface and superficial cortex (right). Hematoxylin and Eosin staining.

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 postoperative 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

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

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

Table 2. — *Energy source comparisons.*

Energy Source Comparison	Adjusted *p*-value for ovarian tissue*	Adjusted *p*-value for uterine tissue*
Bipolar *vs.* ultrasonic	0.82	0.002
Bipolar *vs.* plasma	0.09	0.0002
Bipolar *vs.* monopolar	0.70	0.08
Ultrasonic *vs.* plasma	0.12	0.56
Ultrasonic *vs.* monopolar	0.64	0.18
Monopolar *vs.* plasma	0.02	0.06

**p-values generated using Dunn's test with Benjamini Hochberg adjustment for false discovery.*

enough to injure in two locations without overlap of thermal spread, for a total of 17 ovarian specimens. All specimens were excised to include the area of direct energy application, the adjacent thermal spread zone, and normal tissue for histologic comparison.

Excised tissue was immediately immersed in 10% buffered formalin. After adequate fixation, two of the authors (CB and NL) examined the gross specimens, identified the injured site and submitted 2–3-mm thick sections centering the site of injury. Following routine tissue processing, the tissues were embedded in paraffin then sectioned and stained with hematoxylin and eosin yielding two slides with two tissue sections, per slide, from each specimen. The depth of thermal injury was measured microscopically from the tissue surface to the deepest point of involvement using a calibrated optical micrometer. The thermal effect was recognized by the presence of elongated nuclei with smudgy chromatin and a distinct tinctorial change in the ovarian stroma or uterine smooth muscle that contrasted with the unaffected tissue (Figures 1A-1B). One author (CVB), a subspecialty gynecological pathologist, examined the tissues and recorded the measurements. The pathologist was blinded to the energy sources.

Statistical analysis of the extent of thermal injury with each energy source was performed using one-way ANOVA when data were normally distributed, and the Kruskal-Wallis test for data that were not normally distributed. When statistically significant differences were found, multiple comparisons were then performed using Dunn's test with alpha set to 0.05 and adjustment for false discovery using the Benjamini-Hochberg method. Adjusted *p*-values < 0.05 were considered significant. All statistical analyses were performed in R.

Results

A total of 17 ovarian and 32 uterine specimens were obtained. Two ovarian specimens were excluded, one each in the ultrasonic and bipolar groups, because thermal injury could not be clearly identified histologically. Monopolar electrosurgery resulted in the greatest depth of thermal injury in ovarian tissue (mean 0.99 $\pm$ 0.82 mm), whereas plasma energy produced the smallest depth of injury (mean 0.57 ± 0.4 mm) ($p = 0.018$) (Tables 1 and 2, Figure 2). Differences in thermal injury between other energy sources were not statistically significant.

Among the uterine specimens, the bipolar instrument produced the greatest depth of thermal injury (mean 1.15 ± 0.2 mm). As in ovarian tissue, the plasma device resulted in the lowest level of histologic injury to the uterus (mean depth 0.42 ± 0.13 mm) ($p = 0.0002$ for comparison with the bipolar device). The ultrasonic shears also resulted in a significantly less injury to the uterus than the bipolar device (mean depth 0.48 ± 0.23 mm) ($p = 0.0027$) (Tables 1 and 2, Figure 3). There were no statistically significant differences in depth of thermal injury between the other energy sources.

Monopolar and bipolar electrosurgery appeared, in some cases, to result in severe disruption of the superficial ovarian tissue (Figure 1C). Notably, nearly all ovarian specimens demonstrated injury to the ovarian follicles, which were often within hundredths of a millimeter from the tissue surface.

Discussion

This 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

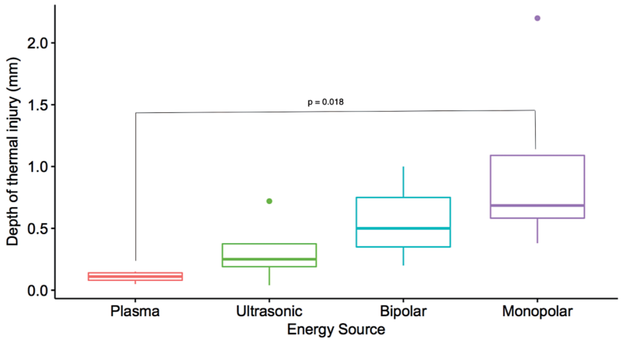

Figure 2. — Median depth of thermal injury in ovarian tissue with first and third quartiles marked. Statistically significant *p*-values obtained using Dunn's test are annotated in the figure.

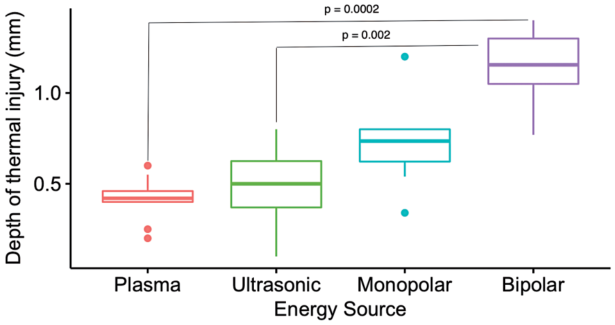

Figure 3. — Median depth of thermal injury in uterine tissue with first and third quartiles marked. Statistically significant *p*-values obtained using Dunn's test are annotated in the figure.

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 the histologic effects of thermal injury on porcine vaginal tissue, which consisted of connective tissue and smooth muscle deep to the epithelium, demonstrated that bipolar devices resulted in more tissue damage than monopolar and ultrasonic devices [18].

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.

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